BIOSTRATIGRAPHY OF THE LOWER ORDOVICIAN CHITINOZOA OF WESTERN NEWFOUNDLAND, CANADA

RANDY S.R. BATTEN

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BIOSTRATIGRAPHY OF THE LOWER ORDOVICIAN CHITINOZOA OF WESTERN NEWFOUNDLAND, CANADA

by

Randy S.R. Batten (B.Sc. Hons.)

A thesis submitted to the

School of Graduate Studies

in partial fulfilment of the

requirements for the degree of

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Memorial University of Newfoundland

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St. John's Newfoundland

ABSTRACT

The Cow Head Group of western Newfoundland, lying exposed within shoreline sections between Bonne Bay and Portland Creek, represents an allochthonous sediment apron or toe deposit at the base of an ancient carbonate-rich continental margin. While it has been studied extensively for a variety of fossil species, few accounts exist for chitinozoa in this stratigraphically important section. For this study, a detailed analysis of samples from 6 sections across the Lower Ordovician Cow Head Group recovered 32 species of well-preserved chitinozoan. In addition, 22 taxa of uncertain specific designation have been identified which represent 9 genera (*Amphorachitina*, *Belonechitina*, *Conochitina*, *Desmochitina*, *Eremochitina*, *Lagenochitina*, *Laufeldochitina*, *Rhabdochitina*, and *Tanuchitina*), and include several species that have never been documented from western Newfoundland.

Frequent occurrence of biostratigraphically useful species (*Amphorachitina conifundas, Conochitina brevis, Conochitina langei, Conochitina raymondi*, *Conochitina symmetrica*, *Lagenochitina esthonica* and *Lagenochitina destombesi*) indicate 4 Lower Ordovician chitinozoan biozones (*Amphorachitina conifundas* Zone, *Conochitina symmetrica Zone*, *Lagenochitina esthonica / Conochitina raymondi* Zone, *Conochitina langei / Conochitina brevis* Zone), and 2 proposed biozones (*Cyathochitina dispar* Zone, *Laufeldochitina* sp. Zone) that are unique to Newfoundland. Together, these zones span the upper Tremadoc through the entire Arenig, and correlate well with equivalent sections from

North America, Europe, north Africa and Australia. While *Amphorachitina conifundas* and *Lagenochitina destombesi* have not previously been reported within North American sections, their persistence in western Newfoundland establishes a strong affinity between Laurentian and Gondwanan sections that has not been documented within eastern Canada.

A preliminary investigation of species distribution suggests a number of taxa (*Conochitina, Rhabdochitina* and *Lagenochitina* spp.) may show preference for either shallow (proximal) or deep water (distal) deposits along the lower carbonate slope of the Cow Head Group. Whether this reflects either physical reworking and sediment transport, or the result of ecological influences is largely speculative. From the present study it is clear that the distributional controls on chitinozoa within the Cow Head Group are indeed complex, and likely influenced by an array of sedimentological and biological processes.

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I am deeply indebted to Dr. Elliott Burden, my supervisor, for suggesting this project and for his invaluable advice, guidance and patience throughout the duration of this research, without which this thesis would never have come to fruition. Dr. Henry Williams kindly provided critical samples for analysis and helped with the production of light micrographs and SEM plates, while Helen Gillespie was gracious in instructing me how to process chitinozoans and prepare SEM stubs. I would also like to thank Carolyn Emerson, Department of Biology, for helping with the SEM photography. Special thanks to Merrell A. Miller, formerly with Amoco Exploration and Production Technology Group, Houston, Texas, for helpful advice and for providing me with a copy of his M.Sc. Thesis and other manuscripts which proved to be invaluable reference material. I would also like to extend my gratitude to Dr. Florentin Paris, University of Rennes, Paris, France for reviewing sections of this thesis and providing helpful advice and suggestions. Further, I would like to thank anyone else who may have contributed to the development of this manuscript in any way. Funding for this research was provided by a Newfoundland Career Development Awards Scholarship, and by a grant from the Provincial Department of Mines and Energy, Newfoundland Branch.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Chitinozoans are a problematic group of extinct, organic-walled microfossils that thrived from Early Ordovician (late Tremadoc) to latest Devonian (latest Famennian) time, and are abundant in marine sediments from the majority of Paleozoic oceans. Described as urn-, tube-, or bottle-shaped, individual tests or vesicles vary in size from 50 to 2000 μm (average 150-250 μm), and may contain processes, spines, warts or other complex ornamentation. Though their tests are hollow, the open end or aperture is often closed by either an operculum or a complex plug. Typically, chitinozoans occur singly or in aggregates, either in chains or in clusters within organic cocoons. Individuals likely originated from groups of connected tests through either the dissociation of chains or the breakup of cocoons (Jansonius, 1967; Jenkins, 1970b; Jansonius & Jenkins, 1978; Miller, 1996). As no contemporary analogue has been found, chitinozoans may represent only parts of life cycles for organisms having planktonic and benthic stages. Several conflicting opinions about chitinozoan affinities have been published, yet the group's systematic position remains speculative. Over the years they have been assigned to protozoans, metazoans, protists, fungi and algae (Miller, 1996). However, traditional placement of the Chitinozoa somewhere within the Protozoa has been challenged recently, as evidence is growing to suggest their origins as metazoan eggs or egg capsules, and even possibly reproductive bodies of

graptolites (Jansonius & Jenkins, 1978; Grahn, 1981b; Paris, 1981). Most recent evidence suggests chitinozoans represent the egg case of a non-preserved, as yet undetermined soft-bodied marine metazoan (Paris & Nõlvak, 1999).

As a group, chitinozoans underwent a rapid evolution during their relatively brief 140 million years of existence. Most species have short ranges, exhibit a wide diversity in form and their geographic distribution is apparently independent of minor facies changes. Many species are also known from a wide variety of depositional environments from virtually every continent, making them an extremely useful correlation tool in the study of Lower and Middle Paleozoic rocks (Jenkins, 1970b). Recent applications of chitinozoan paleontology have expanded outside biostratigraphy and into paleoecology, paleogeography and geothermometry. Unfortunately, the ecological and biogeographic distribution of chitinozoans is complex; while some species show strong ecological or biogeographic controls, others have no definable distribution limits. Though an ongoing endeavour, ultimately resolving the issue of chitinozoan affinity will no doubt shed light on their distributional controls and evolutionary origins (Miller, 1996).

1.2 History of Research

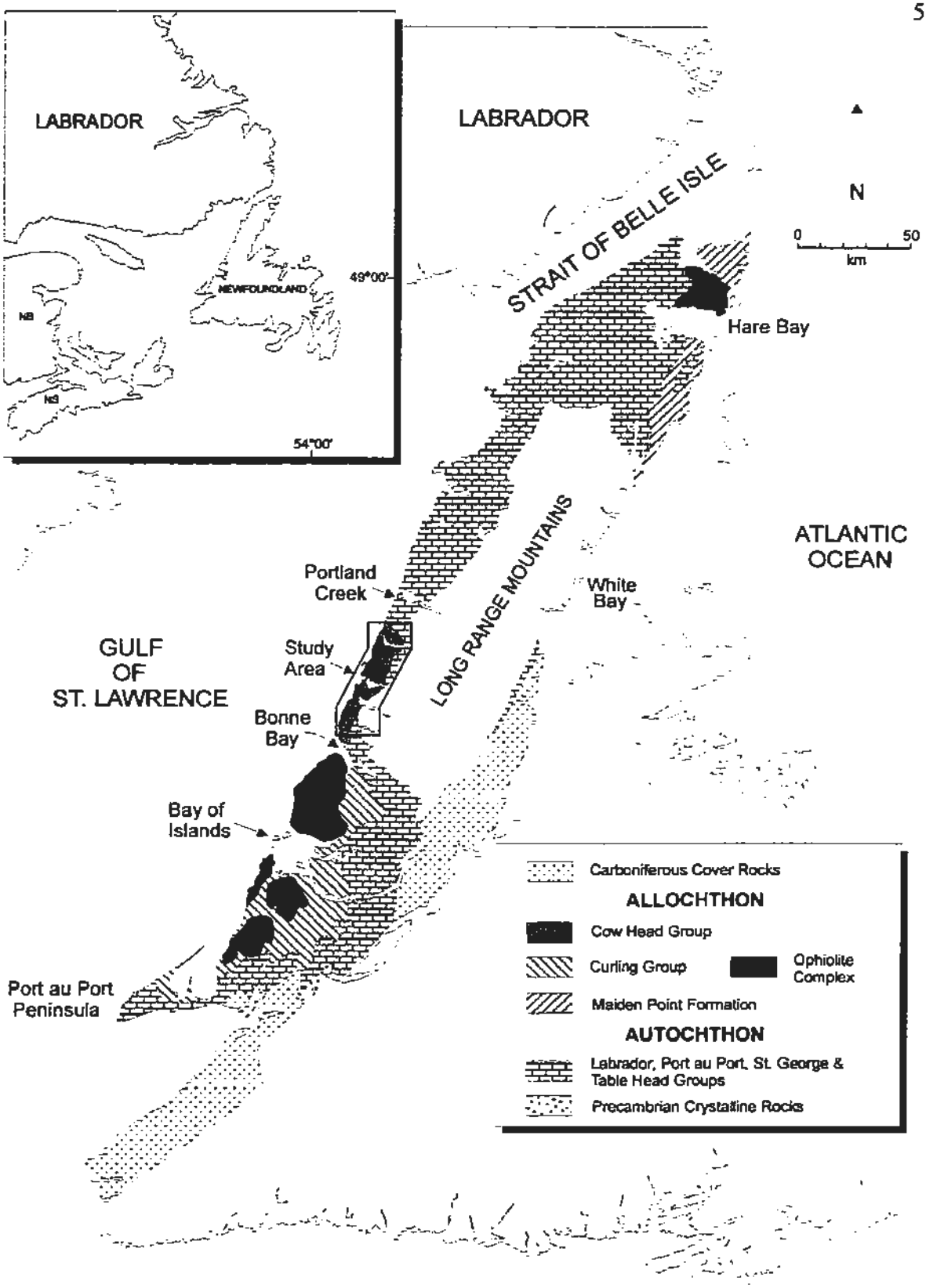
Chitinozoans were discovered and first illustrated by Alfred Eisenack (1930) from Ordovician and Silurian erratics of the Baltic region. During his early work, Eisenack published a series of papers (1931, 1932, 1934, 1937) which provided the groundwork for

subsequent chitinozoan studies. It was during these preliminary studies that Eisenack established a system of classification for the group based upon morphology rather than natural or evolutionary relationships. This system has undergone little modification by most present-day paleontologists and, with slight modifications, forms the backbone of the majority of the current classification systems (Jenkins, 1970b; Jansonius & Jenkins, 1978; Miller, 1996; Paris *et al.*, 1999).

For over forty years Eisenack continued to publish studies of Ordovician and Silurian chitinozoans from Scandinavia and the northeastern Baltic region. However, most research during the 30 years following their discovery was restricted to scattered reports of new occurrences and to developing a formal taxonomy (Jansonius & Jenkins, 1978; Miller, 1996). Reports were published with chitinozoans recorded from North America (Stauffer, 1933; Cooper, 1942), England (Lewis, 1940), and France (Deflandre, 1942, 1945). Eisenack's virtual monopoly on publications was ended in the 1950's by the appearance of a series of papers from Brazil (Lange, 1949) and from the midwestern United States (Collinson & Schwalb 1955; Collinson & Scott, 1958; Dunn, 1959). These papers, and almost all American chitinozoan studies published subsequently, were concerned with Middle Devonian faunas, while European work has been has been devoted almost exclusively to the Ordovician and Silurian (Jansonius, 1969; Jenkins 1970b; Miller, 1996).

During the early 1960's, most new publications were by French paleontologists, and the volume of chitinozoan literature began to grow rapidly (Jansonius & Jenkins, 1978). A large portion of their work involved subsurface material analysis while exploring for oil and

Text-Figure 1.1. Simplified geological map of the Humber (Tectonostratigraphic) Zone of western Newfoundland showing location of study area (redrawn after James & Stevens, 1986).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Carboniferous Cover Rocks
ALLOCHTHON
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Maiden Point Formation
AUTOCHTHON
Labrador, Port au Port, St. George &
Table Head Groups
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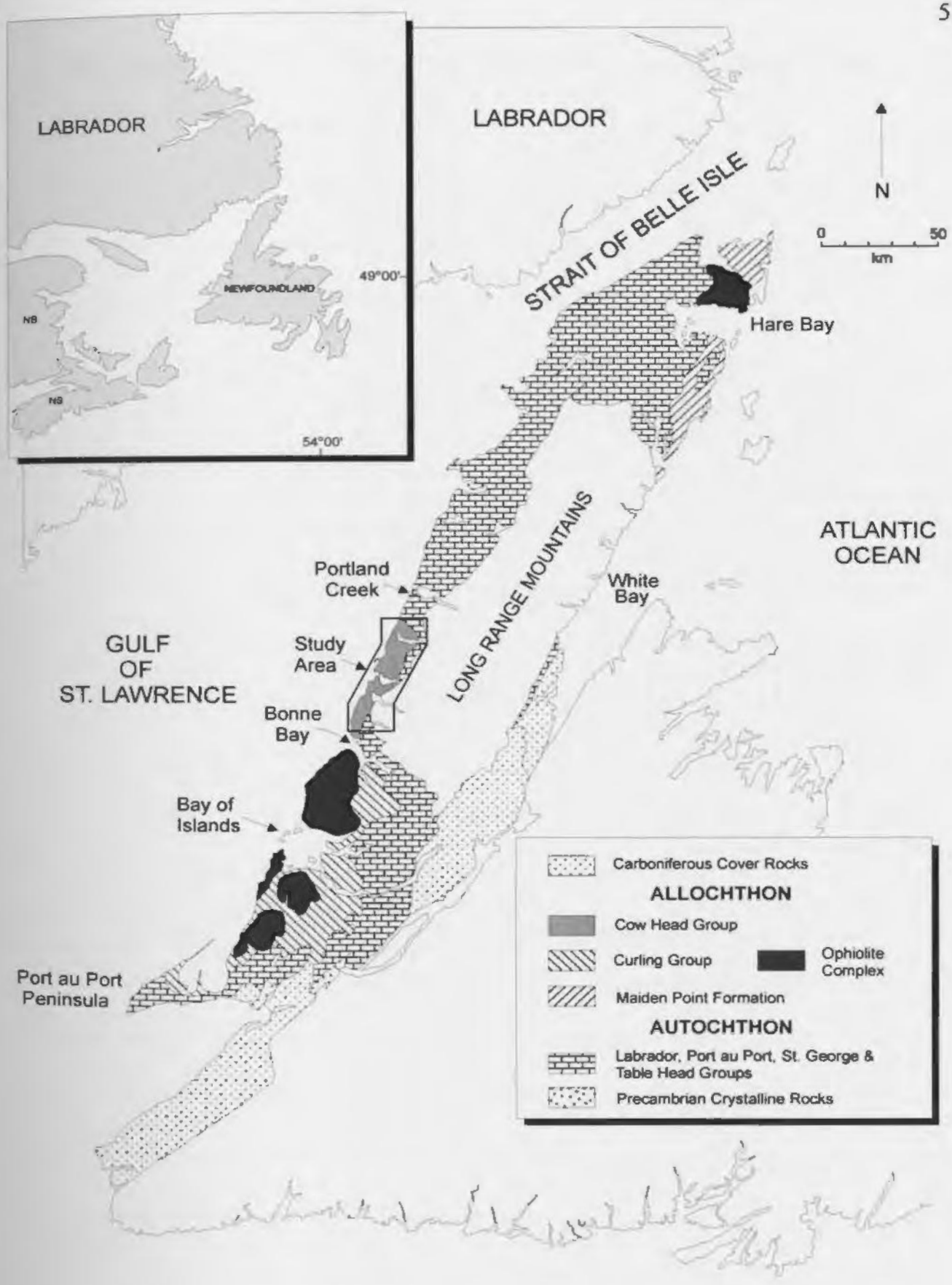
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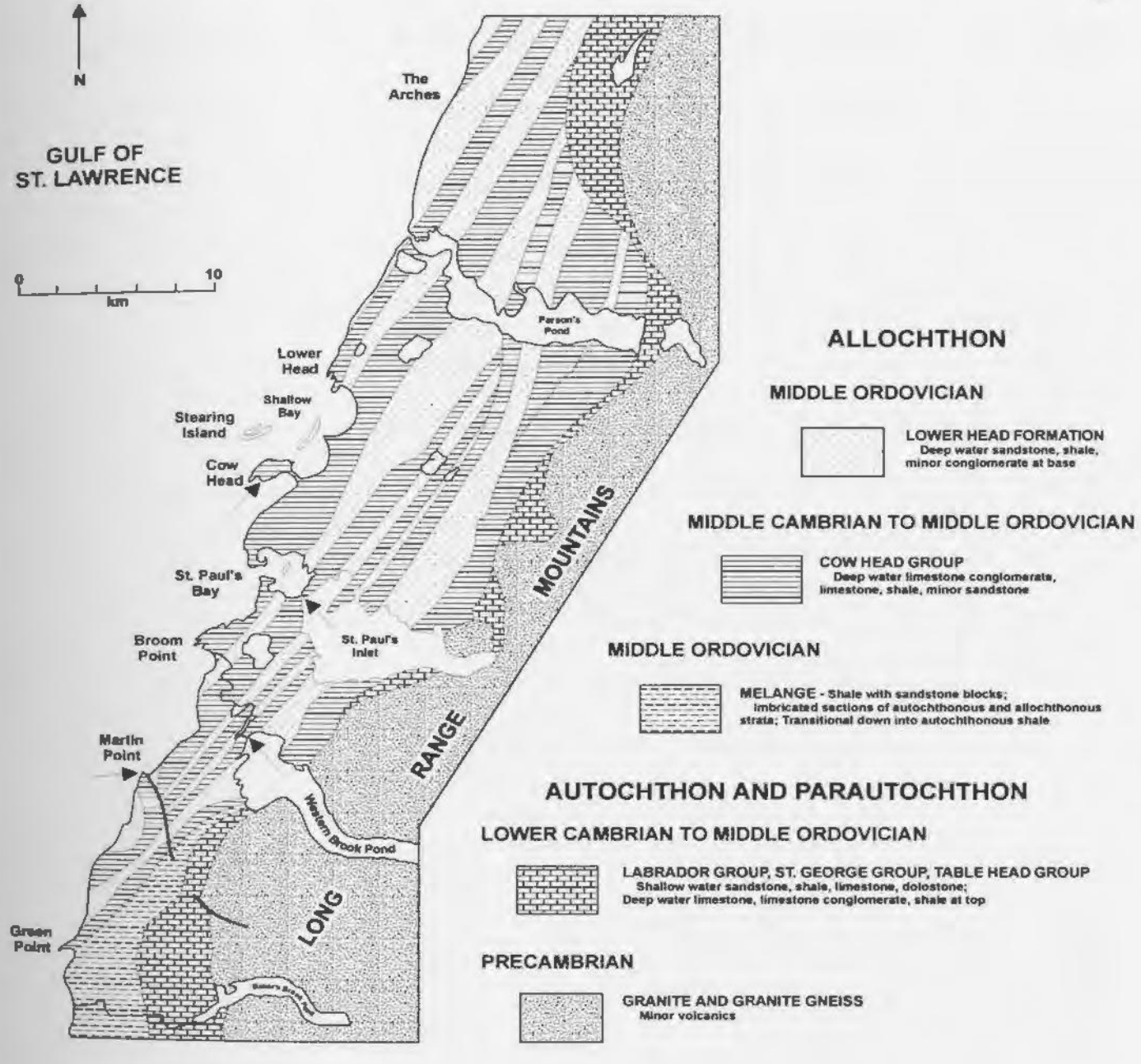


Text-Figure 1.2. Regional map of the distribution of the Cow Head Group and the location (arrows) of sample sites (redrawn from Williams et al., 1985).

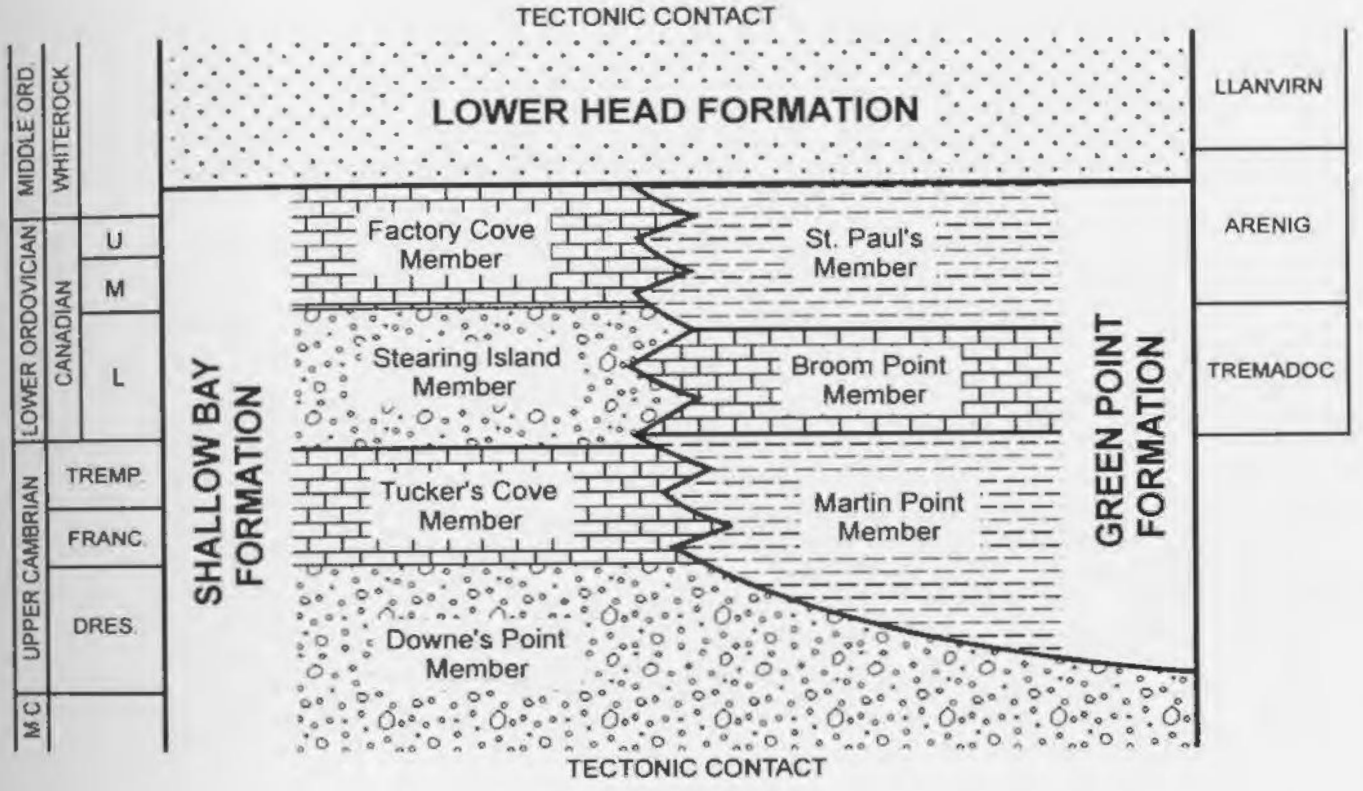
also during this time that chitinozoan reflectance studies were conducted (Bertrand, 1990; Tricker, 1992; Tricker *et al.*, 1992; Cole, 1994) to determine thermal maturation indices. Recently, Miller (1996) and Paris (1996) compiled the sum of twentieth century knowledge on chitinozoan systematics and biostratigraphy.

With the advent of new computer data acquisition hardware and digital imaging technologies (e.g. van Grootel *et al.*, 1993), plus the latest generation of electron microscopy hardware and analytical techniques, future chitinozoan studies will likely involve more extensive analysis of chitinozoan ultrastructure and its biochemical makeup. Recently, Melchin & Anderson (1998) demonstrated the utility of Infrared Video Microscopy in the study of chitinozoan internal morphology. Indeed, knowledge of the vesicle wall composition will be paramount in determine the group's biological affinity. A more rigorous approach to the application of physical and statistical models to the chitinozoan vesicle will inevitably uncover the secrets that shroud this puzzle.

1.3 Geology of the Cow Head Region

1.3.1 Stratigraphy

The Cow Head region on Newfoundland's west coast has been the subject of numerous geological and paleontological studies since the middle of the nineteenth century (Boyce & Williams, 1995). Strata of the present Cow Head Group were first assigned by Logan (1863), based on the field work by Richardson on the Quebec Group. Schuchert &



Text-Figure 1.3. Stratigraphic nomenclature and relationships of units within the Cow Head Group (redrawn from James & Stevens, 1986).

Dunbar (1934) were the first to describe the outcrops on the Cow Head Peninsula and adjacent areas in detail and, subsequently, laid the foundation for geologic mapping in western Newfoundland over the next decade. Though they were originally incorrect in the assessment of the stratigraphic succession of the region, they recognized two separate units in the area: large lenticular masses of coarse breccia on the Cow Head Peninsula, referred to as the Cow Head Limestone Breccia, which formed during the mid-Ordovician Orogeny; and sequences of olive-green shales, grey siltstones and earthy limestones that cropped out at various locations along Martin Point, Broom Point, and St. Paul's Inlet, referred to as the Green Point Formation (Series) of Early Ordovician age. Johnson (1941) later determined that rocks from Green Point to Broom Point, though similar lithologically, were in fact younger than Early Ordovician. Consequently, he removed them from the Green Point Formation and referred to them as the St. Paul's Group. Although Johnson initially defined the greywackes, sandstones and black shales that sit above both the Cow Head and Green Point/St. Paul's groups as the Western Brook Pond Group, he later refined his scheme and replaced it with the Humber Arm Group in an unpublished 1948 map.

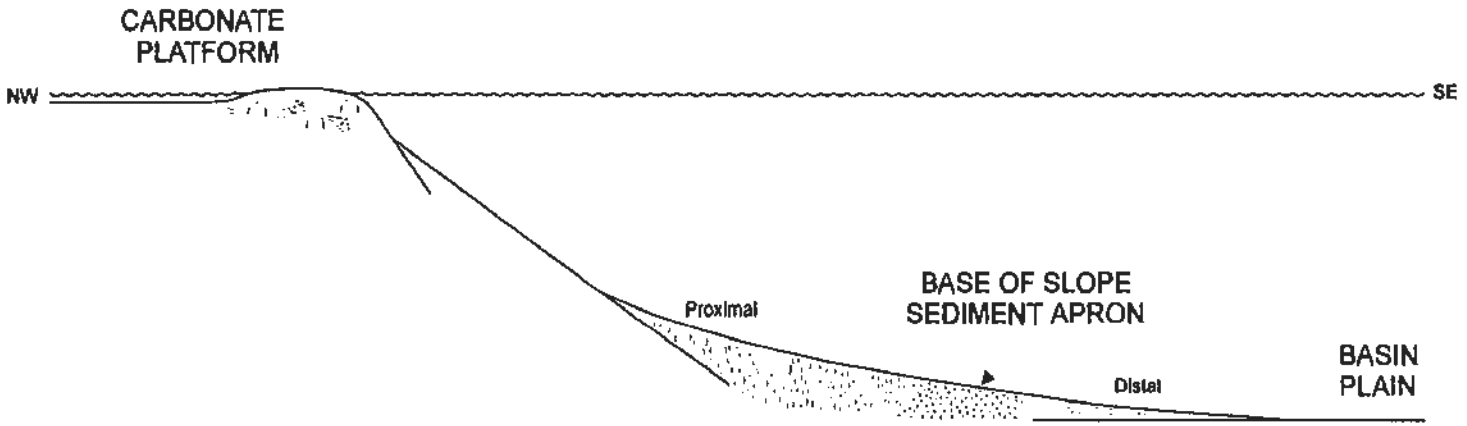
In 1953, Oxley published the first detailed map of the region between Portland Creek Pond and Martin Point using a combination of earlier stratigraphic divisions. In an attempt to accurately redefine the Green Point and St. Paul's groups, he recognized additional lithostratigraphic units of Lower Ordovician age, the St. George /Table Head groups which were similar lithologically to those units first described and named by Schubert & Dunbar (1934) on the Port au Port Peninsula. Later he interpreted the Cow Head Breccia as overlying

both groups.

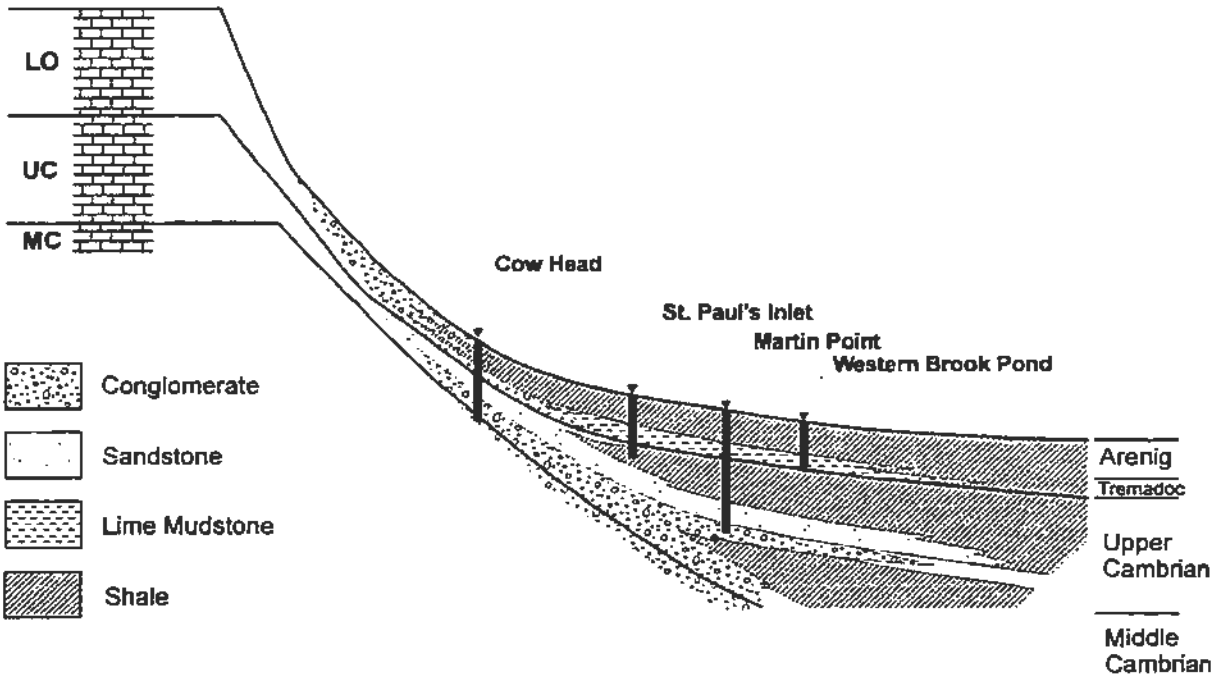
The observations of these early investigators provided the foundations upon which many subsequent studies were conducted. In 1958, Kindle & Whittington provided a detailed sedimentological and paleontological analysis of the region. They defined the Cow Head Group as "about 1000 feet of limestones with interbedded shales and limestone conglomerates with the lowest strata of Middle Cambrian age, and the youngest early Middle Ordovician (Whiterock Stage)". Fossiliferous (trilobites and graptolites) limestone conglomerates and breccias likely represented shallow water deposits, while the shaly beds between the conglomeratic layers were virtually devoid of fossils and likely formed offshore in deeper water. Rather than introduce new names, Kindle & Whittington used the name Cow Head Group as a formal emendation to Schubert and Dunbar's Cow Head Limestone Breccia. Neither did they use any old or propose new names for the green greywackes that overlie the Cow Head, instead referring to them as the "unnamed green sandstone".

During the following years in the late 1960's through to the early 1980's, a number of studies (Stevens, 1970; Williams, 1975; Fortey & Skevington, 1980; Fortey *et al.*, 1982) identified the tectonic setting of western Newfoundland. This led to the idea that the conglomeratic limestone of the Cow Head Group was initially deposited as fossiliferous platformal sediments that were transported to, and subsequently slumped onto the North American margin of the "proto-Atlantic Ocean" (Hubert *et al.*, 1977).

More recently, James & Stevens (1986), and James *et al.* (1987) described the sedimentology and stratigraphy of the Cow Head region in detail. The Cow Head Group is



Text-Figure 1.4. Depositional model showing the Cow Head Group formed as a sediment apron at the base of an ancient shallow-water carbonate platform (redrawn after James & Stevens, 1986).



Text-Figure 1.5. Simplified sketch of the Cow Head Group as a base-of-slope sediment apron schematically showing position of sampled sections (after James & Stevens, 1986).

one of several significant rock units making up the Humber [tectonostratigraphic] Zone of western Newfoundland, which is located beneath a swampy coastal plain lying between the Precambrian Long Range Mountains, and the sea from Bonne Bay to Portland Creek Pond. The strata consist of a succession of limestone, interbedded shale and limestone conglomerate between Middle Cambrian and early Middle Ordovician age, and make up the northern end of the Humber Arm Allochthon. Sediment accumulated as an extensive deep water apron (Text-Fig. 1.3) at the foot of a low latitude, carbonate-rich, early Paleozoic continental shelf, most likely on the margin of the Iapetus Ocean (Williams & Stevens, 1988). Although the sediments comprising the present-day Cow Head Group were transported and deformed during the Taconic orogeny, it maintains a north-west proximal (Shallow Bay Formation) to south-east distal (Green Point Formation) polarity. Through complex shifting of the facies over time, seven distinct lithological units are now identified as members (Text-Fig. 1.3) (James & Stevens, 1986).

1.3.2 Paleontology

Fossils have been recovered from western Newfoundland as far back as the mid-nineteenth century (Dawson, 1883, 1891). During the early part of the twentieth century, Walcott (1916) collected and described a number of Cambrian trilobites from the Cow Head region. A decade later, Raymond (1925) described faunas of lower Middle Ordovician age. Over the next three decades up until the 1950's, a number of additional Cambrian and Lower

Ordovician trilobites were reported and described (Resser 1937, 1942; Kindle, 1942, 1943, 1948; Rasetti, 1954). During the 1950's and 1960's, further reports of trilobite fossils from the Cow Head region were published (Whittington, 1953, 1961), as were reports of brachiopods (Leitch, 1948; Cooper, 1956), corals (Bolton, 1965) and molluscs (Flower, 1952, 1964, 1968). By the late 1960's and into the 1970's, the focus of research temporarily shifted from paleontology into plate tectonics and stratigraphy; Newfoundland's west coast represented a spectacular example of Appalachian geology and orogenesis. In the late 1970's a revitalization of paleontological studies in western Newfoundland began to focus on biostratigraphical correlations with established European strata (Fahraeus, 1970; Boyce & Levesque, 1977; Boyce, 1978, 1979; Erdtmann, 1971, 1986; James & Stevens, 1986).

Although reports of new occurrences of conodont (Bagnoli & Barnes, 1983; Bagnoli *et al.,* 1987), trilobite (Kindle, 1981, 1982; Fortey, 1983; Ludvigsen & Westrop, 1983, 1989; Young & Ludvigsen, 1989; Ludvigsen *et al.,* 1989), algal (James, 1981; Coniglio & James, 1985) and chitinozoan (Nautiyal, 1966; Neville, 1974; Achab, 1989) faunas continued into the 1980's, the focus of the most recent paleontological studies of the Cow Head region have been on graptolite (Williams & Stevens, 1987, 1988, 1991; Erdtmann, 1988; Cooper & Lindholm, 1990; Maletz, 1993; Mitchell, 1992) and conodont (Johnson, 1987; Pohler, 1987, 1994; Pohler *et al.*, 1987; Stouge & Bagnoli, 1988) systematics and biostratigraphy.

With the exception of Neville (1974), Martin (1978) and Achab (1989), very little research has been done on the chitinozoa of western Newfoundland. The goals of this study are **1)** to determine the range of chitinozoan taxa present within the Cow Head region, **2)** to

determine taxonomic correlations [if any] of chitinozoa between regions located at the proximal (Cow Head) and distal (Western Brook Pond) reaches of the ancient continental slope, and 3) to identify biostratigraphical correlations of chitinozoa within the region with other sections from Laurentia and Gondwana. It is the hope of this author that this study will further chitinozoan research and add to a growing database of western Newfoundland paleontology.

CHAPTER 2: MATERIALS & METHODS

2.1 Collecting

Samples of organic-rich shale and limestone were obtained from the Lower Ordovician Cow Head Group, Cow Head, western Newfoundland. Material comes from a reference collection of a previous study of Early Ordovician graptolite biostratigraphy (Williams & Stevens, 1988). Since the Cow Head Group has been extensively mapped and measured, it was possible to obtain representative samples from specific lithologic units of the entire Lower Ordovician. As both chitinozoa and graptolites have been known to co-occur (Jenkins, 1967), samples were selected from those which yielded both abundant and diverse graptolite assemblages. In all, 16 samples were collected from sections of Western Brook Pond (WBN-18A, 29; WBS-23C, 28A, 34, 52A, 62), Cow Head through the Ledge (CHN-9.6BC, 9.17AKZ, 11.4B), Jim's Cove (CHS-11.30, 13.6A), Martin Point (MPS-42C) and St. Paul's Inlet (SPI-431, 55, 78) (see Text-Figs. 5.1-5.6). For clarity in correlation, the sample numbers correspond to those of Williams & Stevens (1988). For future reference, the type material for this study is located at Memorial University's Department of Earth Sciences, Palynology Laboratory, under the auspices of Dr. Elliott Burden.

2.2 Processing

Chitinozoans can generally be recovered fairly easily by standard palynological

methods. However, the techniques employed for this study are based on slight modifications of those described by Jenkins (1967, 1970b), Miller (1967), Grahn (1980), Paris (1981) and Miller (1996). The amount of material to be processed [or recovered] ultimately depended upon chitinozoan abundance and the quality of preservation. Several authors have suggested that 0.5 kg is a good starting point; however, for the present study, 0.5 kg was excessive. Instead, approximately 100 g of material was used. Prior to acid treatment, samples were first crushed to approximately 1-cm (^{3}) cubes (pea size) to speed up dissolution. Jenkins (1967) suggested that 1-inch (^{3}) cubes would be adequate, but again this was found to be excessive and require considerably more effort and time. The crushed samples were then transferred to individually labelled sample bags before acid treatment.

2.2.1 Carbonate Dissolution

Approximately 80-120 g of the crushed rock was placed in 3.8 litre (1-gallon) plastic [polyethylene] buckets and enough (250 ml) dilute (10%) HCl was slowly added to just cover the sample to remove the carbonate component. Slow and careful addition of the acid prevents violent reactions that could damage specimens or cause personal injury. The mixture was gently stirred several times daily, and the reaction allowed to proceed for approximately 5 days (120 hr). Once the reaction ceased, the acid was carefully decanted and the sample given three washes in distilled water. When abundant fine residue resulted, the sample was washed through a 45 μm metal sieve to prevent loss of suspended fossils.

2.2.2 Silica Dissolution

Once the samples were cleared of Hcl and carbonates, enough concentrated (44%) HF was slowly added (250-300 ml) to just cover the sample. Samples were left in the acid until the reaction was complete; about 6 days (144 hr). After the reaction stopped, the HF was carefully decanted and the samples were given three washes in distilled water. Following HF removal and washing, samples were washed over a 45 µm metal sieve and the finished residue that remained on the sieve was stored in 500-ml polyethylene beakers. In several cases large amounts of organic residue remained; this was washed through an additional sieve series (106µm-90µm-75µm-56µm). By partitioning the samples in this manner, it greatly decreased the time taken to pick the fossils from these rich residues. In all but one sample, less than 1% of the original sample remained undissolved.

2.2.3 Picking and Counting

Individual chitinozoans were picked from each residue using a 1-ml Samco® plastic pipette which had been cut off approximately 3 cm from the bulb and a 0.8 x 100 mm capillary tube inserted into it. The bore of this "apparatus" was fine enough to easily extract individual fossils without picking up organic residue. Picked chitinozoans were then stored in distilled water in 7-ml scintillation vials with a few millilitres of 95% ethanol to prevent bacterial and fungal growth. Unfortunately, sporadic occurrences of both rare and frequent chitinozoans did not lend itself to quantifying absolute abundances of taxa with any degree

of consistency. Instead, relative abundances were given (see Text-Figs. 5.1-5.6) and plotted as a range from rare (<10 individuals), moderately abundant (10-20 individuals), abundant (21-50 individuals) and very abundant (>50 individuals).

2.3 Study Material

Nowlan & Barnes (1987) and Williams *et al.* (1998) noted that outcrops within the Cow Head Group are relatively immature, not having been buried deeply or exposed to high temperatures. Most of the chitinozoans recovered during this study were black tests that were only slightly heated and rarely very brittle. Though several individual specimens were slightly translucent, it was insufficient to observe internal detail. Likewise, most tests were also flattened 2-D silhouettes. While no consistent relationship between lithology and state of preservation was evident from this study, many of the 3-D specimens were recovered from thinly bedded, parted and ribbon limestones. With the exception of some of the St. Paul's Inlet and Western Brook Pond North material, individual samples were clean of pyrite (FeS_2) and other minerals.

2.4 SEM Stub Preparation

Well-preserved and three-dimensional chitinozoans were individually picked from the distilled water/ethanol mixture using a Testor's 3/0 (no. 8731) synthetic hair brush and temporarily transferred to 95% ethanol in a 4.5 cm plastic weighing tray prior to placement

on the SEM stub. SEM stubs were then coated with a double-sided adhesive membrane which served both as an adhesive to keep chitinozoans in place, and provide a relatively smooth background devoid of the milling marks present on the surface of uncovered SEM stubs. Using the fine-tipped brush, chitinozoans were then transferred to the surface of the SEM stub and arranged in a circle around the inner perimeter. Though the membrane adhesive was fairly sticky, a few drops of the 95% ethanol facilitated easy movement of the chitinozoans to their final resting place. Soon after mounting chitinozoans, SEM stubs were coated with a gold-palladium alloy, and electron micrographs were taken and developed on Kodak® TMAX 100 (TMX 120) black and white film.

2.5 Light Microscopy

Well-preserved two-dimensional chitinozoans were individually picked from each sample and separated prior to preparation for photography. Depression slides and petri-dishes were initially used both as container and to provide background for the photographs. However, neither provided adequate contrast with the black fossils, even when a background of white paper was placed underneath them. Instead, 4.5 cm (hexagonal) white plastic weighing trays were used which gave not only the best contrast for the developed prints, but also proved to be the best medium for holding and transferring fossils during photography. Light micrographs were taken of individual chitinozoans using a Wild® M400 (1,25x) photomakroskop at approximately eighty times (80x) magnification and AGFAPAN APX 25 black and white film.

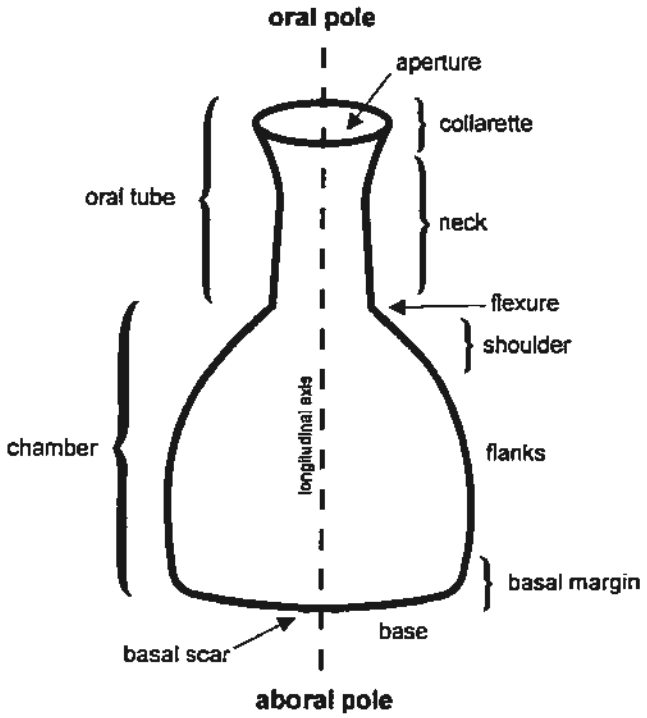
CHAPTER 3: SYSTEMATICS

3.1 Morphology

A detailed review of chitinozoan morphology and systematics will not be presented here as extensive accounts have already been published by Combaz & Poumot (1962), Taugourdeau & Magoire (1965), Jenkins (1970b), Eisenack (1968, 1972b), Jansonius & Jenkins (1978), and most recently by Miller (1996) and Paris (1996), among others. Rather, this section will present a summary of current knowledge, and those interested in a more thorough account are referred to these reports.

3.1.1 General Architecture

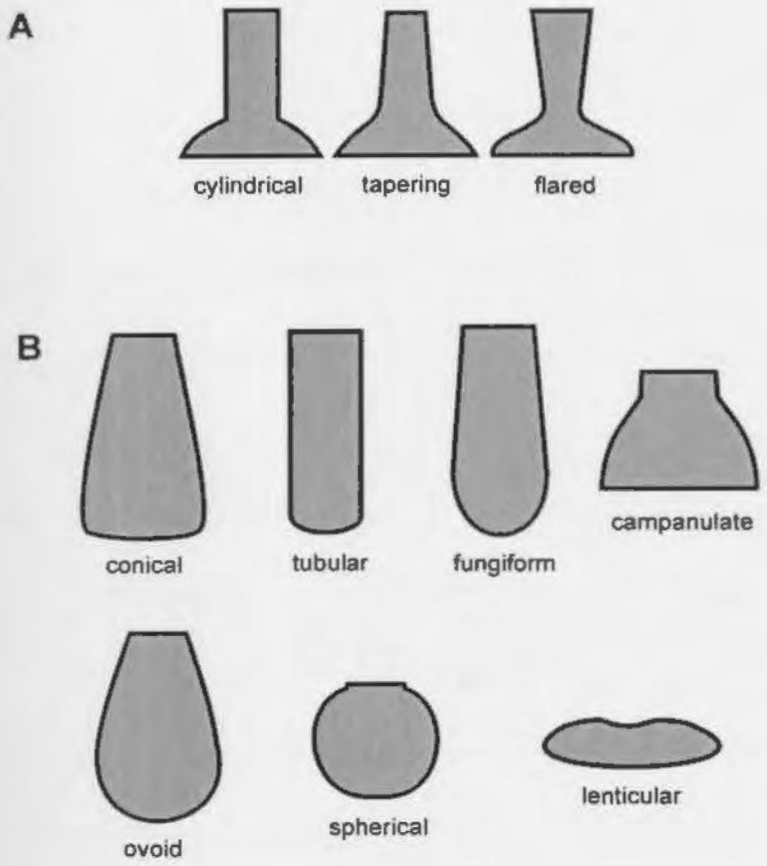
Miller (1996) pointed out that chitinozoan vesicles exhibit a "distinct polarity" with an aperture or opening on the narrower end, while the opposite end is closed and wider. Although no strict convention exists for the orientation of the vesicle, most authors illustrate them with the aperture upward which better facilitates easy comparison between species. The vesicle itself is radially symmetrical about a longitudinal axis and is made up of a body or chamber and an oral tube (see Text-Fig. 3.1). In some species the chamber is only the width of the oral tube and indistinct. In others, like the spherical desmochitinids, the neck is absent and a collarette may be present which sits directly on the chamber. Text-Fig. 3.2 illustrates the characteristic shapes of the chamber showing the base,



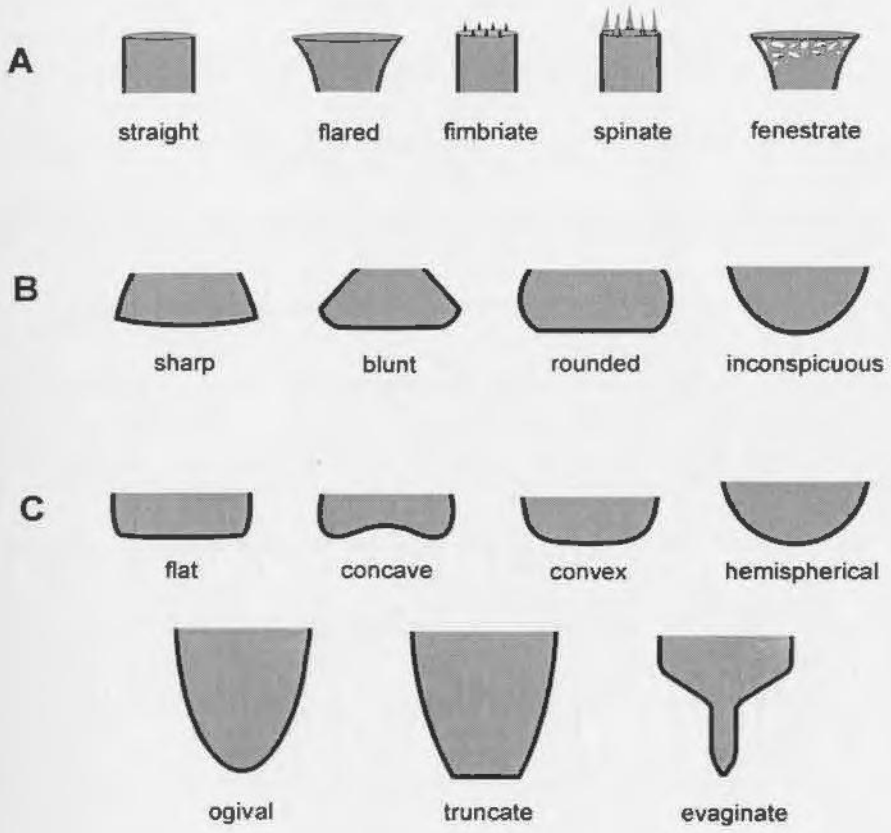
Text-Figure 3.1. A chitinozoan vesicle showing terminology of major structural features (from Miller, 1996; after Jansonius, 1964).

basal edge, flanks and shoulders. Though the base and basal edge are both important in chitinozoan classification, distorting effects of diagenesis and taphonomy (eg. fracturing, mineral growth) can severely alter their appearance. Typically, the base exhibits a variety of shapes. It can be either flat, concave, convex, hemispherical, ogival (sharply ovoid), truncate or evaginate (Text-Fig. 3.3), and most contain a basal scar in the centre. Often the base contains ornament which is more pronounced and elaborate at its edge than towards the basal scar. Additionally, the base may contain one of several elements: a mucron, which is a hollow conical or nipple-like elevation with a central perforation; a copula or a larger tubular structure similar to a mucron; an adherent operculum from an underlying vesicle; some form of extended process; or even a hollow, open-ended siphon extending from the base (Evitt, 1969; Jansonius & Jenkins, 1978; Miller, 1996).

While many chitinozoan species lack ornament on their external surface, many more have elaborate appendices, which can vary in size from a few microns to several times the vesicle's length. Appendices arise as extensions of the basal margin, and range in complexity from very simple to highly branched. In some cases they may be hollow, though no evidence suggests they communicated directly with the chamber interior. This observation has led Laufeld (1974) and Paris (1981) to suggest that appendices may have been deposited by some form of external membrane. Appendices have also been found to co-occur with other types of ornament, either at the shoulder or on the neck. Typically, ornament density is higher around the basal margin, however, in some species (*Ancyrochitina*) higher densities of spines have been observed on the necks.



Text-Figure 3.2. Schematic lateral views of chitinozoan (A) oral tubes and (B) vesicle chambers (after Miller, 1996).



Text-Figure 3.3. Schematic representations of the (A) collarette, (B) basal edge and (C) base (after Miller, 1996).

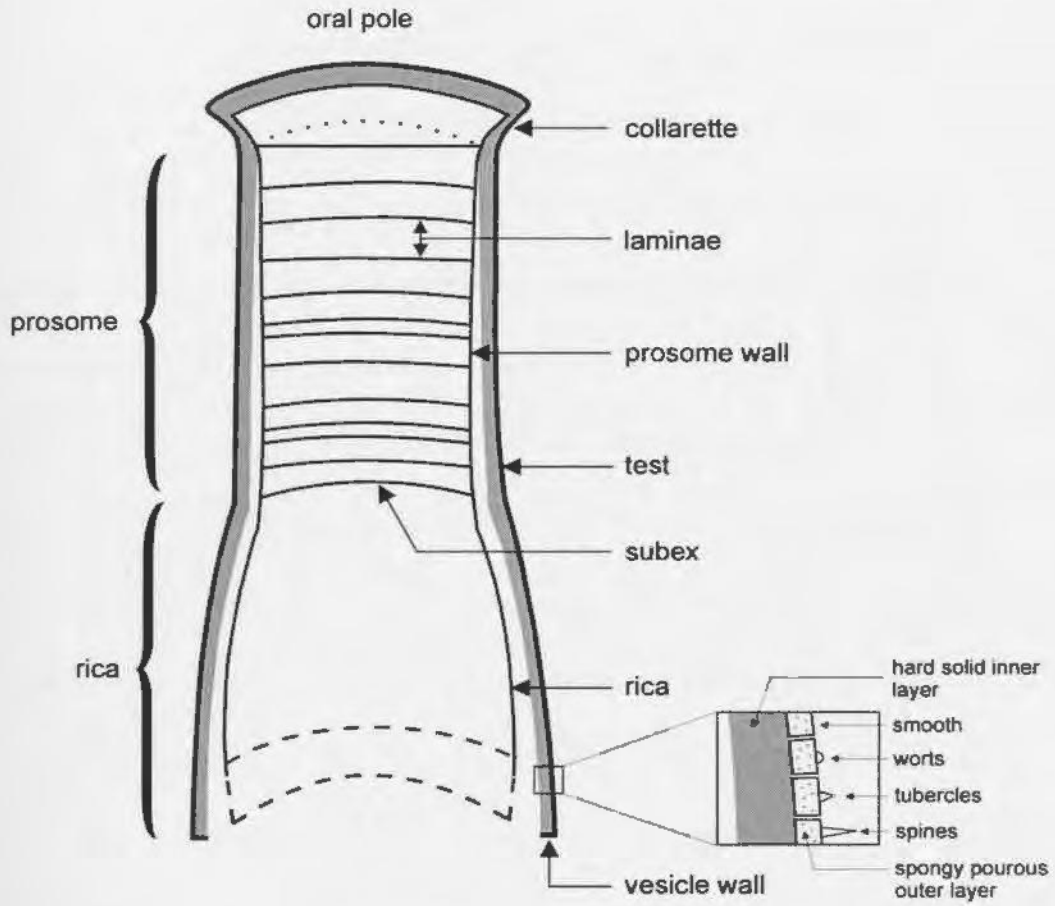
The oral tube, which makes up the rest of the chitinozoan vesicle, consists of two parts: the neck and collarette. It can either be cylindrical in shape or tapered, set off from the body at a juncture known as the flexure, or merge smoothly and imperceptibly with it (Text-Fig. 3.1, 3.2). Typically, the oral tube is less than half the vesicle length, however, vesicles with oral tubes more than half the length are not uncommon; in other individuals it is absent altogether and the collarette sits directly on the body (*Desmochitina*). Like the chamber, the oral tube may possess ornament, which can be either a reduced version of the ornament found on the body or completely dissimilar. The collarette may be distinct and flared or a simple extension of the neck, while its margin may be smooth, possess spines or even be perforated (fenestrate).

The oral end of all chitinozoan vesicles possess an opening or aperture which was sealed by either an operculum or a prosome (Text-Figure 3.4). The operculum is disk-shaped and is located within the collarette, and some have a thickening which corresponds with the basal scar (Jenkins, 1969). Jansonius & Jenkins (1978) suggest that the central pore and concentric ribbing (thickening) reflect the structure of the base to which it was once attached, however, no evidence for a pore or permanent interchamber connection currently exists (Paris, 1981). The prosome, on the other hand, is plug-shaped, made up of a tube with a series of rings or disks, and located within the neck; its length being proportional to the neck length. Structurally, both the operculum and prosome seem to function as a seal. While the purpose of the operculum appears simply in closing, uncertainty still exists about the exact nature of the prosome; Evitt (1969) even suggested that the prosome served a contractile

function. In either case, Eisenack (1968, 1972b) considered the type of sealing structure to be of such fundamental taxonomic importance, he erected two suprageneric categories which are still widely used today, "Operculifera" or those with a lid-like operculum, and "Prosomatifera" or those with a neck plug (prosomes).

3.1.2 Vesicle Wall

Combaz & Poumot (1962) conducted one of the first detailed studies of the chitinozoan wall ultrastructure. Using transmitted light microscopy, they identified three distinct layers within the vesicle wall. While Eisenack's later work (1972b, 1976b) failed to reveal ultrastructural detail, more recent investigations by Laufeld (1974), Grahn & Afzelius (1980) and Mierzejewski (1981) showed conclusively that multiple layers were indeed present. Text-Fig. 3.4 shows a schematic representation of the oral end of a typical chitinozoan vesicle with details of the wall structure. A dense, continuous and smooth inner layer provides the structural support and form, and a porous, spongy or granular outer layer bears the ornament (Grahn & Afzelius, 1980; Paris, 1981). This outer layer, which typically varies in thickness, can be either smooth, scabrate (slightly textured), foveolate (network pattern), feltlike, spongy, verrucate (granules, tubercles or cones < 2 μm high), or possess an assortment of spines. The spine can be quite short and simple, or highly branched distally or proximally (e.g. lambda spines), meshlike, or form vertical rows freely or distally connected (see Paris *et al.*, 1999 for illustrations and details). While the ornament is typically scattered randomly over the vesicle's surface, it can be concentrated around the basal margin



Text-Figure 3.4. Schematic section of neck and prosome complex showing details of the wall structure (redrawn from Miller, 1996).

or arranged regularly in horizontal or vertical rows. On occasion, rows of spines can merge and form longitudinal ridges, which are also produced through the coalescence of external membranes. In several instances (eg. *Velatachitina, Siphonochitina*) a distinct, external layer or "periderm" is developed which, depending upon its complexity, can alter a vesicle's size and shape, and as Miller & Benson (1988) pointed out, possibly has an evolutionary significance.

While the thermal alteration of chitinozoan vesicles has been well-documented (Bertrand & Héroux, 1987; Bertrand & Achab, 1989; Bertrand, 1990; Tricker, 1992; Tricker *et al.*, 1992; Cole, 1994), the exact chemical composition of the vesicle wall remains a mystery. Eisenack (1931) originally referred to the composition of the vesicle wall as chitin, and later, Collinson & Schwalb (1955) suggested it seemed to be composed of pseudochitin. Although Voss-Foucart & Jeuniaux (1972) failed to prove the existence of chitin within the wall of *Cyathochitina campanulaeformis*, they pointed out that this does not necessarily mean chitin was never present, as its persistence throughout the geological record is unknown.

Through the groundbreaking SEM studies of Laufeld (1974), Wrona (1980b), Bockelie (1980) and Paris (1981), more is known about the microarchitecture of the chitinozoan vesicle wall and its possible role in the organism's lifestyle. Unfortunately, the current state of the chitinozoan literature still does not permit definitive conclusions.

3.1.3 Vesicle Distortion

3.1.3.1 Physical Distortion

Aside from the obvious effects of mechanical breakage or fracturing (see Jenkins, 1967; Laufeld, 1967), Miller (1976) pointed out that the most common form of chitinozoan vesicle distortion is caused by compression, which is inherently linked to the process whereby mud is compacted and lithified to form shale. In its most basic form, complete and even compression results in the flattening of a 3-dimensional vesicle, in which, although typically increasing the vesicle's dimensions across the lateral and longitudinal axis, the vesicles proportions usually stay constant, thereby maintaining its taxonomic integrity.

Partial or incomplete compression (Plate 9, figs. 9-11), on the other hand, can alter the dimensions and proportions of a vesicle so drastically, including the loss of taxonomically important surface detail (e.g. ornament), that failure to recognize species and misidentification are inevitable. For instance, in the case of a conical (tapered) vesicle of the genus *Conochitina*, partial compression of the anterior portion of the vesicle (oral tube and neck) gives its silhouette the "illusion" of a being completely cylindrical, which is the major diagnostic feature of the genus *Rhabdochitina*. For this reason, it is important that studies involving chitinozoan taxonomy not rely solely on the results of light microscopy, but also employ the use of SEM and/or TEM techniques, and where possible, other high resolution digital imaging technologies. While neither tool is infallible (this author's own work being

living proof), used in combination they reduce the error and ambiguity inherent in this type of work.

At present there is no accurate model to account for morphological discrepancies within preserved chitinozoans. That is, where does one draw the line between biological variability within a species as compared to the variability among several different species. Unfortunately, the solution to this problem is not forthcoming. However, by examining sufficient material (large statistical samples), one can significantly reduce the error associated with form-based taxonomy. During the course of this study, an attempt was made to predict likely extremes of morphological variants by artificially altering (using computer graphics manipulation) a vesicle's dimensions proportionally with the observed trends in distortion. While the results were inconclusive, they showed potential application and could likely be the subject of future work.

3.1.3.2 Chemical Distortion

Chemical effects have also been linked to chitinozoan vesicle distortion. Miller (1976) identified internal pyrite framboids (irregular shaped pyrite scales) within the wall structure of specimens of *Cyathochitina hyalophrys*, and discussed the possibility that the unusual granular surficial textures observed in some other chitinozoan vesicles (Taugourdeau & DeJekhowsky, 1960; Taugourdeau, 1966; Legault, 1973; Wood, 1974; Laufeld *et al.*, 1975) were the result of pyrite framboid growth forming a "secondary

overprint". Earlier, Jenkins (1970b) illustrated a "honeycomb" ultrastructure in the wall of *Acanthochitina barbata* which were most likely the result of compressed pyrite framboids on the vesicle's surface. Likewise, within this study, several samples from St. Paul's Inlet and Western Brook Pond (south) were heavily pyritized resulting in unusual nodular (angular and spheroid) surface textures within a number of specimens, which presented much difficulty during the identification process (Plate 9, figs. 2, 5).

3.1.3.3 "Biological" Distortion

First reported by Eisenack (1931) who interpreted them to be the result of either fungal or bacterial action, chitinozoan vesicle wall perforations have been documented throughout the entire organism's existence, from the Ordovician (Eisenack, 1931, 1932, 1968, 1972b; Jenkins, 1967, 1969; Laufeld, 1967; Wrona, 1980b), Silurian (Eisenack, 1972a; Laufeld, 1974) and Devonian (Wrona, 1980a, 1980b). Although no causative agent has been positively identified, Laufeld (1974), Wrona (1980b) and Grahn (1981c) have described and illustrated three types of geometric perforations that seem to occur fairly regularly on the wall of chitinozoan vesicles: cylindrical, conical, and stepped-conical (see Miller, 1996 for discussion). While Grahn (1981c) illustrated hemispherical cysts on the surface of *Rhabdochitina gracilis* and *Desmochitina amphorea* which he speculated were ectoparasites (resembling ciliates and amoeba) that bored into the vesicle wall for nutrition, Cashman (1991) interpreted these bodies as abiologic. However, Martin

(1971) showed that abiological perforations can be caused either chemically through pyrite disentegration, concomitantly with fractures, or during processing.

Although the origin of surficial chitinozoan vesicle perforations has not been ascertained conclusively, Laufeld (1974) pointed out that large Silurian conochitinids were more frequently perforated than other genera. Similarly, Vogel *et al.* (1987) identified a correlation between types and frequency of borings (eg. fungal, algal) in marine brachiopods and corals and oxygenation levels, suggesting for the first time the potential of "parasitic" borings for paleoecological interpretation (Miller, 1996).

3.2 Biological Affinities

Assigned to virtually every major biological group, the biological affinities of chitinozoans represents an interesting enigma. While ornament, oral tube structures, wall ultrastructure, and even mode of occurrence (abundance, diversity, type stratum) have all been used to derive a valid model of chitinozoan biology, the fact that the simple overall shape of chitinozoan vesicles has evolved frequently throughout the plant and animal kingdoms has lead to a plethora of theories. Chitinozoans have been placed within either protists, protozoans, metazoans and fungi (Miller, 1996). Although some very recent papers (Geng *et al.*, 1997; Gabbott *et al.*, 1998) have provided significant new evidence, the present state of their biological and evolutionary affinities is still quite tenuous.

Eisenack (1931) originally suspected that chitinozoans might be related to testacean

rhizopods, but because testaceans live entirely in fresh water and their tests are easily dissolved in KOH, he eventually withdrew his proposal (1932). Later that year, Eisenack proposed an affinity with ciliate protozoans, a theory that was shared by Deflandre (1942). More recently, Reid & John (1981) compared chitinozoans to tintinids, noting their obvious similarities, but also pointing out that tintinids have not been observed to form chains.

Kozlowski (1963) discussed the idea that chitinozoan vesicles were analogous to eggs or cysts within organic-walled sheaths ("cocoons"). He rejected the notion that they share an affinity with protozoans because they did not display any similar test arrangement within a "cocoon", and considered that chitinozoans were far more structurally complex than eggs or egg capsules.

While Obut (1973) proposed that chitinozoans could be related to dinoflagellates, and Locquin (1976, 1981) treated them as belonging to fungi, the unique morphology often exhibited by chitinozoans precludes their assignment to either group. Taugourdeau (1981) concluded that "too many original features were present within chitinozoans for them to be assigned to either protists, protozoans or metazoans" (Miller, 1996).

Recently, Cashman (1990, 1991) revamped the idea that chitinozoans share an affinity with rhizopod protozoans, and cited several examples of a previously undocumented juvenile stage. However, Miller (1996) was "unconvinced" by Cashman's reasoning, pointing out an obvious anachronism within his proposed chitinozoan life cycle; cocoons were absent in strata younger than Ordovician, and in those containing chitinozoans they are

of a type that lacked mucrons, a feature Cashman (1990) argued as playing an integral role. Further, only very rarely have intermediate size chitinozoans, from the small (10 μm) "juveniles" to the much larger "adults", ever been recovered. As growth would be implicit within any life cycle, one would logically expect to see representatives from intermediate stages. Cashman (1991) explained this absence by suggesting a rapid growth stage in the organisms ontogeny.

In the face of heated debate and speculation, the "metazoan egg hypothesis" has remained popular for explaining chitinozoan biology, and one that has recently been gaining support (Grahn, 1981b; Paris, 1981; Dzik, 1992). Jenkins (1970b) first noticed the morphological similarities between graptolite and chitinozoan remains and pointed out that their stratigraphic ranges overlap. While similar degrees of diversity and abundance of graptolites and chitinozoans in a given unit appear to support the contention that chitinozoans may represent the graptolite pre-prosicular stage, Paris (1981), Paris *et al.* (1981) and Kríz *et al.* (1986) found no correlation between their diversity in Silurian/Devonian beds of Bohemia. In a similar study, Grahn (1984) found no correlation in abundance between chitinozoans and Caradoc cystoids. However, in this study samples of organic-rich shales were selected because of their graptolite diversity and abundance (Williams & Stevens, 1988), which yielded similarly abundant and diverse assemblages of chitinozoans (see Chapter 4, Table 4.1). While this may further lend support to their affinity for graptolites, it should be cautioned that because the Cow Head Group represents a clear mixing of

transported shelf, slope and basinal sediments and fossils, conclusions drawn on such associations are tenuous at best.

Shortly after Jenkins (1970b) proposed his chitinozoan/graptolite affinity hypothesis, Laufeld (1974) proposed that chitinozoans were in fact eggs, and that the ornament and appendices were deposited as an external membrane, although he did caution that chitinozoans may in fact be a polyphyletic group. Indeed, linear and coiled egg chains are common in a number of marine molluscs and polychaetes (Kozlowski, 1963; Laufeld, 1974; Paris, 1981, Brusca & Brusca, 1990; Dzik, 1992). Grahn & Afzelius (1980) even suggested that the wall ultrastructure of a chitinozoan vesicle was adequate justification that chitinozoans were metazoan eggs.

Earlier this decade, Jaglin & Paris (1992) and Miller & Williams (work in progress, fide Miller, 1996) concluded that bizarre teratological chitinozoans could not have been produced through normal biological processes (eg. budding), but rather were derived from an unknown, oviparous "chitinozoophoran" (Grahn, 1981a), a theory that Hart (1989) had shared. Instead of exhibiting a normal growth pattern with intermittent stages, "These eggs developed and reached maturity within the parent organism, and were liberated within the marine environment with a definite size and morphology" (Grahn, 1981b).

Although the debate over chitinozoan affinity is ongoing, a recent series of reports (Geng *et al.*, 1997; Gabbott *et al.*, 1998; Paris & Nõlvak, 1999) have provided further evidence that chitinozoans may actually represent an ontogenic stage (e.g. eggs) in the life

cycle of an as yet unknown, non-fossilisable soft-bodied metazoan. Even in the absence of a "parent animal", it appears to be the most compelling explanation of chitinozoan biology and species level biodiversity. Still, it should be cautioned that it is not yet universally embraced.

While the results of this study suggest that chitinozoans and graptolites may share an affinity, they are speculative and inconclusive. It is my belief that the variety of forms exhibited by the chitinozoans within the present work are best explained as the skeletal remains, possibly reproductive structures, of an unknown soft-bodied invertebrate, rather than as a plant or fungal structure.

3.3 Paleoecology

Like other aspects of chitinozoan biology, the paleoecological implications of this enigmatic group are varied and speculative. Although relatively few accounts have dealt specifically with chitinozoan paleoecology, most favour a planktonic lifestyle. Indeed their exclusively marine existence in shallow water deposits, as well as their abundance in slope and outer shelf deposits where passive planktonic elements (e.g. spores, fragments of tracheids) are extremely rare or absent altogether, their persistence in deposits devoid of benthic or endo-faunas (e.g. anoxic Silurian black shales), and their wider geographic distribution than known benthic or neritic faunas, all lend support to this theory (Miller, 1996). Paris (1996) noted that some chitinozoan taxa even extend across paleoclimatic belts.

The presence of appendices, carina and flanges of many species (eg. *Ancyrochitina fragilis*) were all inferred to increase buoyancy, much like present-day sarcodine (radiolarian) protozoans (Brusca & Brusca, 1990). Their wide geographic distribution in concert with their occurrence in a variety of rock types (Collinson & Schwalb, 1955; Laufeld, 1967) provides further argument for the planktonic nature of some chitinozoans. However, elongated individuals with smooth test walls such as *Conochitina minnesotensis* or *Rhabdochitina magna* lack the morphological features typically associated with a floating existence, which suggests that chitinozoans may have existed in both the benthic and planktonic realms (Laufeld, 1974; Grahn, 1982b).

Miller (1996) recently discussed several examples of recurrent [chitinozoan] species associations (RSAs) from the upper Edenian and Maysvillian stages (Cincinnati Series, Upper Ordovician) of the Cincinnati, Ohio area. These show a succession from species-diverse "deeper water" (eg. *Hercochitina*) assemblages, to successively "shallower water" (eg. *Calpichitina* and *Cyathochitina*) associations.

Similar ecological models of species associations and their relation to sequences that reflect water depth have previously been discussed by Jenkins (1969, 1970a) and Bergström & Grahn (1985). They showed that species assemblages with one or more elements of *Calpichitina lata*, *Belonechitina micracantha* or *Cyathochitina campanulaeformis*, among others, persisted in either a shallow carbonate ramp or tidal to offshore facies, which would indicate that environment played an important role in the distribution of chitinozoans. In a

similar study, Grahn & Miller (1986) showed that *Calpichitina lata* formed an important part of a diverse species assemblage in "deeper water" facies of the Bromide Formation, Arbuckle Mountains, southern Oklahoma, and that the shallow water deposits of the Pooleville Member were devoid of chitinozoans.

Although too few reports exist to permit definitive conclusions about environmental controls on chitinozoans, Paris (1996) recently discussed how it was possible to assess environmental influence by measuring several parameters, including: the abundance of individuals (expressed in number of specimens per gram of rock); the taxonomic diversity (number of species and genera recorded); the relative frequency of every species or form (as a percentage of the whole "population" of chitinozoans); and the ratio of chitinozoans to other residual palynological components (including spores, acritarchs, scolecodonts, leiospheres and tracheid fragments). Paris (1996) also pointed out a number of consistencies that, though not universally true, may help in further explaining chitinozoan biology. In particular, the highest production of chitinozoans seem to occur in high latitude cold water, while reefs are not generally favourable for their accumulation. Further, the taxonomic composition of chitinozoan assemblages appears to be environmentally controlled (certain species are specific to deep water, outer shelf environments, while others are common within shallow water, near-shore settings), and that more passive elements (spores and tracheid fragments) are generally regarded as indicators of near-shore environments and inversely proportional to chitinozoan abundance.

During the course of this study, I investigated the possible geographic and paleoecological distribution of chitinozoans across the Lower Ordovican Cow Head Group of western Newfoundland. While no clear-cut statistical patterns were evident, the larger, bottle-shape vesicles (lagenochitinids) tended to be more abundant around sections of Cow Head and St. Paul's Inlet, which are located proximally on the slope, while smaller cylindrical and conical individuals tended to have higher abundances around the distal locales at Western Brook Pond. If this trend reflects the natural distribution of chitinozoans, several explanations are possible. Assuming the present distribution is post-depositional, gravity flows and/or underwater currents may have physically sorted the vesicles, with the smaller ones moving farther down the slope. Alternatively, this may indicate a preference of the larger chambered individuals for shallower water, which in turn would support their planktonic existence, while the preference for deeper water for the smaller individuals which do not possess a swollen, potentially "buoyant" chamber could support a benthic lifestyle. Although the converse could also apply, this trend towards a benthic or planktonic existence is speculative and inconclusive. Undoubtedly there are numerous complexities associated with the environmental controls on chitinozoan distribution within the Cow Head Group, and that more than one physical or biological process is at work.

CHAPTER 4: SYSTEMATIC PALEONTOLOGY

4.1 Introduction

In 1931, Alfred Eisenack established a system of chitinozoan classification based strictly on morphological characteristics rather than on shared phylogenetic or evolutionary traits. Originally, he proposed three families (Lagenochitinidae, Conochitinidae, Desmochitinidae) to include the seven genera he described (*Lagenochitina*, *Angochitina*, *Acanthochitina*, *Conochitina*, *Rhabdochitina*, *Mirachitina*, and *Desmochitina*); however, *Mirachitina* is no longer considered a chitinozoan. Several authors later proposed modifications to Eisenack's original familial scheme (Wilson & Dolly, 1964; Jansonius, 1964, 1967, 1969; Taugourdeau, 1965; Tappan, 1966; Eisenack, 1968, 1972a), however, none received wide acceptance. Though the ideas put forward by Eisenack still largely remain unchanged and form the basis for most current chitinozoan classification schemes, Miller (1996) maintained that the uncertainty surrounding the group's biological affinity and ambiguity concerning the function of the vesicle (as either a complete living organism or part of a reproductive cycle) posed an enduring problem in the development of a universally embraced suprageneric classification.

While strict morphological or form-based taxonomy has limitations, it does provide an adequate framework for comparing and classifying taxa which have traditionally been illustrated as dark [blackened] 2-dimensional silhouettes. Several authors have attempted to

use the prosome/rica complex and the development of the vesicle wall as a basis of a classification scheme. However, with the exception of some of the more recent accounts that show an increase in the use of SEM analysis, few published reports on chitinozoans have illustrated specimens in sufficient detail to be of any significant practical use.

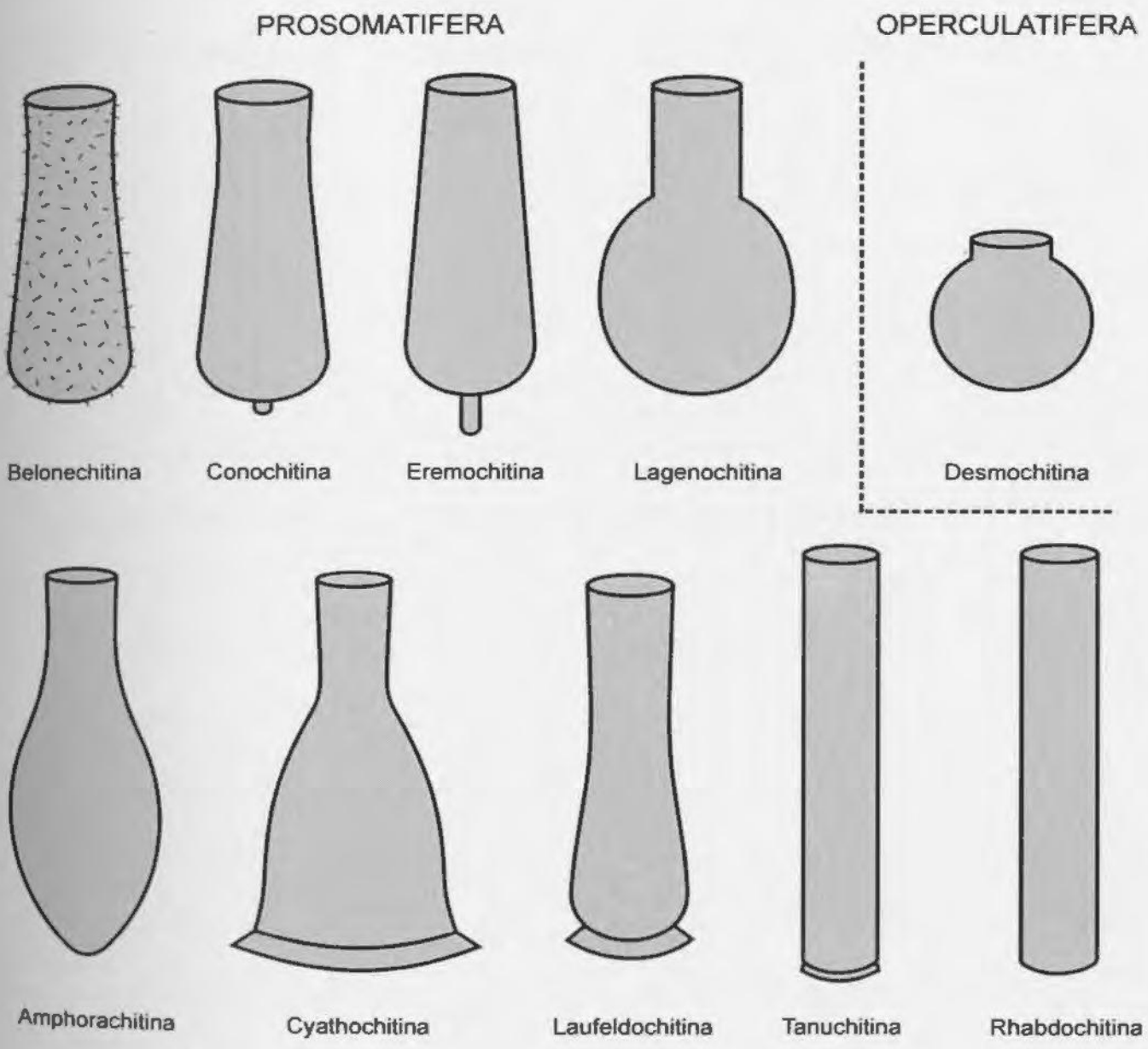
For the present study, I found that form taxonomy worked well with few difficulties. However, as Miller (1976) pointed out, if applied on a strict basis, form taxonomy can lead to a rapid proliferation of species, particularly in cases where only one biological species is likely represented. Consequently, I did not consider slight variation in overall size and silhouette shape to be as important taxonomically as the mode of occurrence (e.g. singly or in chains), type of ornament and processes, and characteristics of the oral and aboral poles.

Within the numerous published and unpublished chitinozoan reports, taxa are either arranged alphabetically or under a version of Eisenack's (1972a) suprageneric classification scheme (eg. Paris, 1981), each following the International Code of Zoological Nomenclature (ICZN) (Miller, 1996). Jenkins (1970b) and Laufeld (1974) noted that supporters of the alphabetical listing question the validity of a suprageneric classification scheme for an extinct group of organisms whose affinity is still shrouded in uncertainty. Rather, they suggest that for a small number of genera, an alphabetical arrangement is more appropriate.

At present, orders are the highest taxonomic subdivisions used to classify chitinozoa. The Operculatifera possess a lid-like operculum, have reduced oral tubes, usually with a collarette sitting directly on the chamber which typically lacks a neck. The Prosomatifera

possess a plug-like prosome and have well developed necks, typically with well-formed flexures (Text-Fig. 4.1). Under the familial classification scheme of Miller (1996), the Operculatifera contains only one family, the Desmochitinidae, and six subfamilies. The Prosomatifera contains two families that differ primarily in the relation between neck and chamber. The twelve subfamilies (six in each family) are defined by the type and arrangement of ornament and structures on the base or basal edge.

Within the Prosomatifera, distinctions among forms assigned to the genus *Conochitina* (Eisenack, 1931) and morphologically similar genera are somewhat controversial and often only subtle variation exists among some taxa. Consequently, I have chosen to follow the taxonomic scheme proposed by Paris (1981) and Achab *et al.* (1993) and later modified by Miller (1996), which uses the descriptive terminology proposed by Combaz & Poumot (1962) and The Commission Internationale de Microflore du Paléozoïque, Subcommission on Chitinozoa (see Figs. 3.1-3.3). Here, *Conochitina* includes conical vesicles with smooth tests. *Belonechitina* and *Hercochitina* (Jansonius, 1964) include those forms with discrete spines covering the test, in whole or in part, or those with longitudinal spines that may be interconnected at their apices, respectively. Further, Achab (1980, pp. 228-230) erected a new genus, *Fustichitina*, which includes elongate, conical forms with a hemispherical to oval shaped base. It is my opinion, as was the opinion of Paris & Mergl (1984), and several others, that this genus does not exhibit characteristics that make it distinctive enough to be placed into its own taxon. Consequently, I have chosen to omit



Text-Figure 4.1. Schematic representation of genera discussed in text (objects not drawn to scale; redrawn from Paris, 1981).

this name. Species formerly placed within this genus by Achab are presently returned to the genus *Conochitina*.

The taxonomic nomenclature and subdivisions for this study follow those of Miller (1996), with the modifications and emendations by Paris (1981), and recently by Paris *et al.* (1999). For the most up to date and detailed description of families, subfamilies and genera, individuals are referred to the latter reference.

4.2 Descriptions

Formal standardized methods for describing chitinozoan vesicles have yet to be established. However, in keeping with the vast majority of chitinozoan research, descriptions shall include, but not be limited to, **1)** the overall vesicle shape with details of the oral tube and chamber, **2)** the shape of the basal margin and base, and **3)** details of the vesicle wall, including surficial features (ornament) and ultrastructure (if visible).

Vesicle size, shape, ornament and type of sealing structure are all important characteristics used to describe and classify chitinozoans because they are features of vesicles that usually maintain consistency within each genera and related taxa. The type and complexity of surface ornament is very important taxonomically, because it is often defines both genera (e.g. *Belonechitina, Hercochitina*) and species. However, the importance of size alone should not be overstated, as the "parent" organism was no doubt capable of growth with individuals exhibiting a variety of size ranges. Ratios between standard measurements

(e.g. ratio of vesicle width to length) are also important taxonomically because they are not typically affected by large variations in size and they reduce discrepancies in measurements caused by slight physical distortions between individual vesicles. Because observation of internal detail within a chitinozoan vesicle are affected by the state of preservation and both the type and degree of processing, it is not as reliable a tool as examining a vesicle's external features. Likewise, it should be cautioned that while ratios are generally consistent, they are not immune to errors caused by vesicle distortion. Recently, the use of SEM observations in chitinozoan studies has helped greatly to increase the accuracy of identifications. While SEM observations are preferred to transmitted-light observations for resolving fine and intricate surficial detail, I do not share Paris' (1981) belief that only SEM observations are adequate for biostratigraphic work.

4.3 Measurements

All measurements have been recorded in micrometers (μm), and include the following characteristics (see Text-Fig. 3.1):

1) ***Maximum length*** - from oral pole to aboral pole, exclusive of processes or ornament

2) ***Maximum width*** - across lateral dimension from left to right

3) ***Aperture width*** - diameter of the extreme oral end

4) ***Oral tube length*** - length of the oral tube from aperture to flexure (where applicable)

5) ***Neck width*** - diameter of the oral tube below the aperture, typically represents the narrowest point on the vesicle

In those individuals in which the oral tube (neck) and chamber merge imperceptibly (eg. some conochitinids), measurements for the oral tube length and neck width have been omitted. Morphological terms in quotations (" ") refer to a structure which is indistinct or poorly defined. Where applicable, descriptions and measurements for distinctive ornament will be included.

4.4 Synonymy Lists

Where possible detailed up-to-date synonymy lists have been given. The first author cited provided the original diagnosis by naming and describing the first occurrence of the species or by reclassifying an existing taxon, while subsequent authors reported additional accounts of the species with any changes to its formal name. In cases where a question mark occurs within the synonymy list, either the reported species name falls into a different genus but very closely resembles the holotype, or a species described under the same name bears little resemblance to the holotype. Where only one author has been reported, either the taxon was recently erected and its name is still intact, or a detailed synonymy list could not be generated from available literature.

Table 4.1. List of Arenig and Tremadoc chitinozoans recovered from the Cow Head Group, western Newfoundland (*taxa are listed alphabetically according to subfamily).

Desmochitina sp. **A**
Desmochitina sp. **B**

Belonechitina sp.

Conochitina brevis (Taugourdeau & DeJekhowsky 1960)
Conochitina chydea (Jenkins 1967)
Conochitina decipiens (Taugourdeau & DeJekhowsky 1960)
Conochitina dolosa (Laufeld 1967)
Conochitina sp. cf. ***C. dolosa*** (Laufeld 1967)
Conochitina sp. cf. ***C. elegans*** (Eisenack 1931)
Conochitina homoclaviformis (Taugourdeau 1961)
Conochitina kryos (Bockelie 1980)
Conochitina langei (Combaz & Péniguel 1972)
Conochitina sp. cf. ***C. langei*** (Combaz & Péniguel 1972)
Conochitina minnesotensis (Stauffer 1933)
Conochitina ordinaria (Achab 1980)
Conochitina pervulgata (Umnova 1969)
Conochitina poumoti (Combaz & Péniguel 1972)
Conochitina sp. cf. ***C. poumoti*** (Combaz & Péniguel 1972)
Conochitina raymondi (Achab 1980)
Conochitina simplex (Eisenack 1931)
Conochitina subcylindrica (Combaz & Péniguel 1972)
Conochitina symmetrica (Taugourdeau & DeJekhowsky 1960)
Conochitina turgida (Jenkins 1967)
Conochitina ventriosa (Achab 1980)
Conochitina sp. **A**
Conochitina sp. **B**
Conochitina sp. **C**
Conochitina sp. **D**
Conochitina sp. **E**

Rhabdochitina magna (Eisenack 1931)
Rhabdochitina tubularis (Umnova 1976)
Rhabdochitina usitata (Jenkins 1967)
Rhabdochitina sp.

Eremochitina sp. cf. ***E. baculata*** (Taugourdeau & DeJekhowsky 1960)

Laufeldochitina sp.

Tanuchitina sp.

Amphorachitina conifundas (Poumot 1968)
Amphorachitina sp.

Lagenochitina sp. cf. ***L. baltica*** (Eisenack 1931)
Lagenochitina boja (Bockelie 1980)
Lagenochitina capax (Jenkins 1967)
Lagenochitina combazi (Combaz & Péniguel 1972)
Lagenochitina cylindrica (Eisenack 1931)
Lagenochitina destombesi (Elouad-Debbaj 1988)
Lagenochitina esthonica (Eisenack 1955b)
Lagenochitina maxima (Taugourdeau & DeJekhowsky 1960)
Lagenochitina sp. cf. ***L. maxima*** (Taugourdeau & DeJekhowsky 1960)
Lagenochitina obeligis (Paris 1981)
Lagenochitina sp. cf. ***L. ovoidea*** (Benoit & Taugourdeau 1961)
Lagenochitina tumida (Umnova 1969)
Lagenochitina sp.

Cyathochitina calix (Eisenack 1931)
Cyathochitina dispar (Benoit & Taugourdeau 1961)
Cyathochitina sp.

4.5 Taxonomy

Order OPERCULATIFERA Eisenack 1972b

Family DESMOCHITINIDAE Eisenack 1931, emend. Paris 1981

Subfamily DESMOCHITININAE Paris 1981

Genus *Desmochitina* Eisenack 1931, emend. Paris 1981

Type species: *Desmochitina nodosa* Eisenack 1931

Remarks. Eisenack's (1931) original definition of the genus *Desmochitina* was very broad and general, and according to Paris (1981), could have encompassed a vast number of taxa. Jansonius (1964) first restricted the genus in order to separate it from *Hoegisphaera* (Staplin, 1961) by imposing that "the vesicle width not exceed the length, base convex and lacking a copula or basal callus". However, the condition that the base lacks a copula or basal callus is contrary to Eisenack's diagnosis. While illustrations of the type species show it possessing a distinct callus, Laufeld (1967), among others, did not agree with Jansonius' restriction. Though some authors did not consider this as critical, Paris (1981) felt that restricting this definition to forms resembling the type species was warranted and less ambiguous. Under his revised definition, the genus *Desmochitina* includes: "spherical to ovoid chambered chitinozoa lacking a neck, but with a collarette that is sometimes well developed; test smooth, rugose or with fine tubercles but lacking spinose ornament; aboral pole with a very short mucron connected to the operculum of the preceding vesicle; simple discoid operculum at the oral margin or the base of the collarette; chains consistently abundant."

Although restrictive, Paris' (1981) emended definition of the genus *Desmochitina* still shared slight similarities with other stout conical or ovoid chambered chitinozoa, particularly *Calpichitina* (Wilson & Hedlund, 1964), *Eisenackitina* (Jansonius, 1964), *Bursachitina* (Taugourdeau, 1966), and *Urnachitina* (Paris, 1981). However, *Urnachitina* is more elongate and less spherical and has a larger tubular copula with a well developed basal peduncle, while *Bursachitina* is more conical in shape and *Calpichitina* is more lenticular. *Eisenackitina* has a similar form to *Desmochitina* but possess spines or tubercles on its external wall.

***Desmochitina* sp. A**

Plate 3, fig. 18.

Description. Small, subspherical vesicle with very short cylindrical collarette sitting directly on the chamber. Chamber ovoid, wider than long (ratio of length to width approximately 1.2:1), with maximum diameter at the midpoint. Basal margin inconspicuous, base hemispherical to rounded and lacking a copula or callus. Vesicle wall appears slightly granular but lacks distinct ornament.

Dimensions.

Overall length:	194 (199) 207 μm
Overall width:	166 (174) 187 μm
Oral tube length:	--
Neck width:	--
Aperture width:	115 (128) 134 μm
# specimens measured:	3

Remarks. *Desmochitina minor* (Eisenack, 1931) is a relatively common Ordovician chitinozoan whose range extends into the Arenig, however, it typically has a more conically shaped collar and its outer wall is often ornamented with spinose thickenings or verrucae (Laufeld, 1967). Further, *D. minor* has its longest dimension on the longitudinal axis rather than across its lateral dimension. Individuals assigned *Desmochitina* sp. A. closely resemble Eisenack's (1931) holotype of *Desmochitina nodosa* (70-90 µm long), but are larger. While the presence of a distinct basal callus is typically characteristic of *D. nodosa*, individuals which lack this structure are not uncommon (Laufeld, 1967). Eisenack suggested the possibility that the overall shape of *D. minor* and *D. nodosa* grade into one another with transitional forms sharing characteristics from both species. Laufeld (1967) later pointed out that the variation in form of *D. nodosa* was so great that in many of his unbleached specimens, it was impossible to distinguish the species from *D. minor*. The similarities between *D. minor* and *D. nodosa* (wall structure, basal callus) may indicate that the two forms represent extremes of only one taxon. Unfortunately, this can only be inferred and not proven from this study. *D. nodosa* has only been reported from Caradocian localities (Eisenack, 1931, 1962a; Laufeld, 1967; Schallreuter, 1981), giving little credibility to an affinity with *Desmochitina* sp. A. While *D. minor* has been recovered from Arenig strata, the rarity of specimens, lack of detailed surficial features and large size do not permit a specific assignment.

Occurrence. Tremadoc: Martin Point South (MPS 42-C), *A. victoriae* Zone; **Arenig:**

Western Brook South (WBS 23-C), *D. bifidus* Zone.

Desmochitina sp. **B**

Plate 3, fig. 19.

Description. Elongated chain of distorted subspherically shaped vesicles, each with an oral to aboral connection with adjacent individuals.

Dimensions.

Overall length:	1040 μm
Individual length:	64 (82) 99 μm
Individual width:	113 (148) 163 μm
Oral tube length:	--
Neck width:	--
Aperture width:	?
# specimens measured:	6

Remarks. The form of *Desmochitina* sp. B as a series of vesicles in a chain is consistent with the form exhibited by many species of desmochitinids, particularly *D. minor*. Unfortunately, the distorted shape of the individuals making up the chain and lack of visible diagnostic features does not permit specific assignment of this specimen.

Occurrence. Tremadoc: Martin Point South (MPS 42-C), *A. victoriae* Zone.

Order PROSOMATIFERA Eisenack 1972b

Family CONOCHITINIDAE Eisenack 1931, emend. Paris 1981

SUBFAMILY Belonechitinidae Paris 1981

GENUS *Belonechitina* Jansonius 1964

Type species: *Belonechitina robusta* (Eisenack) Jansonius 1964

Syn.: *Conochitina micracantha robusta* Eisenack 1959

Remarks. Jansonius (1964) erected two new genera, *Belonechitina* and *Hercochitina*, to include those individuals which were formerly included within the genus *Conochitina*, but which bear distinct ornament over its surface. While *Belonechitina* shares the same basic shape as *Conochitina*, (conical, typically with weak separation of neck and chamber, a rounded basal margin and convex to rounded base), it is distinguished in having spinose ornamentation over all or part of its vesicle surface. Unlike *Hercochitina*, the ornament of *Belonechitina* is distributed randomly (irregularly) over the surface rather than in parallel longitudinal rows. Laufeld (1967) and Eisenack (1968, 1972b) did not consider ornamentation alone to constitute a valid generic criterion, especially since a complete gradation from a smooth wall to a highly ornamented wall has been observed in many individuals. Paris (1981) noted that within any species possessing ornamentation, SEM analysis shows that even the so-called "smooth" forms typically possess tiny spines on their lower flanks. It was on this observation that Paris considered *Belonechitina* to be a valid genus; an opinion that was also shared by Melchin (1982) and Miller (1996), and one that is adopted here.

Belonechitina sp.

Plate 3, fig. 24.

Description. Large conical vesicle with a short, weakly cylindrical neck approximately 20 to 25% the total length, that merges almost imperceptibly with the chamber. Collarette slightly flared. Flexure and shoulders absent. Flanks largely straight and widen towards the base with maximum diameter at the basal margin. Base flat to concave, basal margin rounded. Vesicle wall has an extremely small spinose or granulated pattern on its surface.

Dimensions.

Overall length:	769 µm
Overall width:	301 µm
Oral tube length:	--
Neck width:	--
Aperture width:	172 µm
# specimens measured:	1

Remarks. *Belonechitina* sp. possesses very tiny spinose ornament which was observed using light microscopy. Although it shares features with Achab's (1982) holotype of *Belonechitina pirum* from the upper Arenig of the Levis Formation (Zone D) of Quebec, *Belonechitina* sp. is about 40% larger and does not contain sufficient detail in ornament to assure specific designation.

Occurrence. Arenig: Cow Head South (CHS 13.6-A), *I. v. maximus* Zone.

Subfamily CONOCHITININAE Paris 1981

Genus *Conochitina* Eisenack 1931

emend. Paris, Grahn, Nestor, and Lakova 1999

Type species: *Conochitina claviformis* Eisenack 1931

Remarks. Eisenack first erected the genus *Conochitina* in 1931 and later revised his definition in 1955a and 1965. Taugourdeau (1966) decided that sufficient variability existed within *Conochitina* that he segregated two additional genera, *Bursachitina*, and *Euconochitina*. Eisenack (1968) noted that more intra-specific variation existed than could be accounted for by both genera defined by Taugourdeau and hence, ranked them as subgenera. Later, Eisenack (1972a) redefined *Bursachitina* to include short, conical to bulbous forms lacking ornament, and reinstated it to the rank of genus.

The genus *Euconochitina* was originally distinguished from *Conochitina* on the presence of a basal mucron. Because this feature does not appear consistently in all conochitinids (e.g. *C. minnesotensis*), this separation was not sufficiently justified. Subsequently, the genus *Euconochitina* was not adopted by later workers. Jansonius (1964) restricted the definition of *Conochitina* by separating those forms with distinct spines or rows of spines into *Belonechitina* and *Hercochitina*, respectively.

In keeping with Paris' (1981) restricted definition, the genus *Conochitina* will herein include those forms which are conical to cylindroconical (= claviform) in shape, with an indistinct neck and chamber, a flexure which is absent or poorly defined, and a convex to slightly rounded base, with maximum diameter typically occurring at the basal margin. The

smooth test wall, which may or may not posses a (well-developed) basal mucron, does not bear discrete spines, processes, granules or reticulum.

Conochitina brevis (Taugourdeau & DeJekhowsky 1960)

Plate 1, figs. 1-5.

Conochitina brevis Taugourdeau & DeJekhowsky, 1960, p. 1222, pl. 3, figs. 47-49; Benoit & Taugourdeau, 1961, p. 1405, fig. 2; Taugourdeau, 1961, p. 139, pl. 1, fig. 12; Doubinger, 1963a, p. 126, pl. 1, fig. 6; Bouché, 1965, p. 154, pl. 1, figs. 4, 5; Gao, 1968, pl. 4, fig. 14; Martin, 1969, pl. 2, fig. 28; ?Umnova, 1969, pl. 1, figs. 18, 19; Achab, 1986a, p. 687; pl. 2, fig. 10.

Euconochitina brevis Rauscher, 1968, p. 54; pl. 2, figs. 11-13.

?*Conochitina* sp. Achab, 1981, pl. 4, fig. 14.

?*Eisenackitina uter* Martin, 1983, p. 17, pl. 4, figs. 6, 13.

?*Lagenochitina combazi* Playford & Miller, 1988, p. 24, pl. 3, fig. 6 (non figs. 3-5, 7-9).

Description. Stout conical to cylindroconically shaped vesicle with indistinct oral tube. Orally, the vesicle tapers slightly towards the aperture which terminates in a straight, indistinct collarette. Flanks are slightly curved, almost straight, and widen to maximum diameter just above the basal margin. Base convex to slightly flattened, basal margin rounded. Vesicle wall smooth.

Dimensions.

Overall length:	281 (334) 360 μm
Overall width:	148 (175) 192 μm
Oral tube length:	--
Neck width:	--
Aperture width:	94 (129) 147 μm
# specimens measured:	20

Remarks. *Conochitina brevis* (Taugourdeau & DeJekhowsky, 1960) is distinct and not easily confused with other typically more elongate conochitinids. While it shares similarities with atypical forms of *Desmochitina minor* (Eisenack, 1931), *C. brevis* does not have a regular spherical or ovoid form. Rather, it is noticeably tapered at the aperture and lacks a distinctly flared collarette which sits directly upon the chamber, typical of the majority of desmochitinids. While *C. brevis* shares a silhouette with *Eisenackitina*, the wall of *Eisenackitina* is distinctly covered with spines.

Occurrence. Arenig: Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 34), *I. v. maximus* Zone.

Stratigraphic Distribution. Taugourdeau & DeJekhowsky (1960) originally described *Conochitina brevis* from Zones 0_2 and 0_3 (Ordovician-Gotlandien) of the Sahara. In the following year Benoit & Taugourdeau (1961) described specimens from North Africa, presumably from Arenigian (?) sections. Since then the species has been recovered from other European sections, including the Silurian of Aquitaine (Taugourdeau, 1961), the Lower

Ordovician (Arenig) to Lower Silurian (Llandovery) of the Djado Basin, Nigeria (Bouché, 1965), the Lower-Middle Arenig of Montagne Noire in the south of France (Rauscher, 1968), the Upper Arenig (Huy-3) of Condroz, Belgium (Martin, 1969), and from the Russian Platform within the Leetse, Volkhov and Tallinn (Arenig-Llandeilo) horizons (Umnova, 1969). In North America, *C. brevis* has been recovered from the Levis Formation, Zone C (middle Arenig) of Quebec and the Cow Head Group (Arenig) of western Newfoundland, Canada (Achab 1986a).

Conochitina chydea (Jenkins 1967)

Plate 1, figs. 6-8.

Conochitina chydea Jenkins, 1967, p. 453, pl. 70, figs. 4-8; Andress *et al.*, 1969, p. 369, pl. 1, fig. 1; Atkinson & Moy, 1971, pl. 2, figs. I, J; Neville, 1974, p. 194, pl. 1, figs. 2(?), 3(?), 4(?), 5-12, 16-18, 22-24 (non figs. 13-15, 19-21, 25-27); Martin, 1978, p. 76, pl. 12.1, fig. 14; Paris, 1981, p. 178, pl. 12, figs. 10, 14, pl. 13, fig. 18, pl. 17, fig. 3; Melchin, 1982, p. 183, pl. 6, figs. 7, 11, 12.

Conochitina cf. *chydea* Paris, 1979, p. 30; Paris, 1981, p. 180; pl. 16, fig. 10.

?*Conochitina* Nautiyal, 1966, p. 315, pl. 27, figs. 18-20, pl. 28, figs. 3, 4.

Description. Stout conical or cylindroconical vesicle with short, subcylindrical to weakly flared neck about one third the total length. Collarette typically straight. Flexure present but weakly defined, shoulders absent. Flanks slightly curved and widening to maximum diameter

at the basal margin. Base convex and basal margin well rounded to inconspicuous. Wall smooth.

Dimensions.

Overall length:	345 (361) 387 µm
Overall width:	153 (170) 182 µm
Oral tube length:	128 (136) 144 µm
Neck width:	86 (92) 98 µm
Aperture width:	106 (117) 123 µm
# specimens measured:	10

Remarks. Jenkins' (1967) original description and illustrations of *Conochitina chydea* showed that the species is slightly more elongated and fungiform than the Cow Head material, though he noted that the test has considerable variation in shape, with "the chamber being slender or stout, and the neck absent or up to nearly half the total length". Further, most of the populations examined by Jenkins contained both smooth and ornamented individuals [bearing small cones], which was also observed by Neville (1974) from the Table Head Formation, western Newfoundland. While this feature was not visible in present material, it could easily have been destroyed during preservation or absent altogether.

Occurrence. **Tremadoc:** Martin Point South (MPS 42-C), *A. victoriae* Zone; **Arenig:** Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 78), *I. v. maximus* Zone.

Stratigraphic Distribution. Jenkins (1967) described the species from the Hope Shales and the *Onnia* Beds (Llanvirn-upper Caradoc) of the Welsh Borderland, Shropshire. Paris (1979)

recovered several specimens from the Louredo Formation (Llandeilo) and base of the Porto do Santa Anna Formation (Lower Caradoc) of the Buçaco syncline, Portugal, and later (1981) recovered them from the Cacemes and Louredo formations (early Llanvirn-early Caradoc) in Portugal, the Grès Armoricain Formation (upper Arenig-lower Llanvirn) and Andouille Formation (Llandeilo), Massif Armoricain, and from the Séville Province (Ashgill) of Spain. Similar specimens, referred to as *Conochitina* cf. *chydea*, were also found in the Buçaco syncline of Portugal, and rare forms were recovered from the lower Caradoc at the base of the Louredo Formation. In the Massif Armoricain, the Pont-de-Caen Formation (lower Caradoc) also yielded rare *Conochitina* cf. *chydea* near Domfront (Paris, 1981). In North America, *C. chydea* has been recovered from the base of the Llanvirn to the base of the Caradoc in North-Central Florida, U.S.A. (Andress *et al.*, 1969), the Table Head Group (Caradoc), Port au Port Peninsula (Neville, 1974), the Cow Head Group, Cow Head Peninsula (Arenig) and the Middle Table Head Formation (Llanvirn) of western Newfoundland, Canada (Martin, 1978), and from the uppermost lower Bobcaygeon to uppermost Lindsay [Rocklandian to lowest Maysvillian (Caradoc)], Simcoe Group, southern Ontario, Canada (Melchin, 1982).

Conochitina decipiens (Taugourdeau & DeJekhowsky 1960)

Plate 1, figs. 9-12; Plate 7, fig. 1.

Conochitina decipiens Taugourdeau & DeJekhowsky, 1960, p. 1222, pl. 4, figs. 50-54; Gao, 1968, pl. 1, fig. 7; Rausher, 1973, p. 70, pl. 6, figs 1-3, pl. 7, fig. 1(?); Achab, 1980,

p. 224, pl. 1, figs. 9-11; Paris & Mergl, 1984, p. 44, pl. 2, figs. 5-7; Achab, 1986a, p. 689, pl. 2, figs. 1-3; Grahn, 1992, p. 712, fig. 7, nos. 2, 3.

Clavachitina decipiens Taugourdeau, 1966, p. 35; Rausher, 1968, p. 52, pl. 1, figs. 2-7.

?*Lagenochitina magnifica* Umnova, 1969, p. 336, pl. 2, figs. 25, 26.

?*Conochitina* Nautiyal, 1966, p. 314, pl. 27, figs. 13-16.

Description. Conical shaped vesicle with subcylindrical to weakly conical oral tube that merges imperceptibly with the chamber. Aperture slightly flared and wider than the "neck", collarette indistinct. Flexure and shoulders absent. Flanks convex and widen until just above the basal margin where they form the maximum diameter. Basal margin rounded and slightly swollen in the lower quarter; base flat, convex or slightly concave. Wall smooth.

Dimensions.

Overall length:	508 (553) 589 µm
Overall width:	123 (146) 172 µm
Oral tube length:	–
Neck width:	86 (92) 99 µm
Aperture width:	108 (119) 146 µm
# specimens measured:	10

Remarks. Though the original description of the species given by Taugourdeau & DeJekhowsky (1960) was brief, "subcylindrical, aborally swollen; base flat; aperture indistinct", they observed sufficient variability within the population to propose four potential morphological variants; subcylindrical; elongated conical; bulging; and swollen. Whether this variability represented one biological species or different taxa is presently

unclear. Unfortunately, their description did not provide precise information about size variation or the appearance of surface features. Taugourdeau (1966) later erected the genus *Clavachitina,* and included within it forms previously described as *Conochitina decipiens*; however, Achab (1980, p.224) did not think this was sufficiently justified. From Taugourdeau & DeJekhowsky's (1960) illustrations of *C. decipiens*, it appears that the test is smooth and more appropriately belongs to the genus *Conochitina* as emended by Paris (1981). Paris & Mergl (1984) stated that the species is difficult to identify due to lack of distinctive features, a problem encountered with the Cow Head material. Present specimens of *C. decipiens*, however, are consistent with the original diagnosis of Taugourdeau & DeJekhowsky (1960) and descriptions and size ranges of Achab (1980; 1986a) and Paris & Mergl (1984) who all recovered it from Arenig strata.

Occurrence. Tremadoc: Martin Point South (MPS 42-C), *A. victoriae* Zone; **Arenig:** Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; Western Brook South (WBS 28-A), *I. v. lunatus* Zone.

Stratigraphic Distribution. The species has been described from Zones 2 and 3 (Lower Ordovician-Gotlandien) of the Sahara, south of Algeria (Taugourdeau & DeJekhowsky 1960), the Lower-Middle Arenig, Montagne Noire, southern France (Rauscher, 1968, 1973), the Klabava Formation (Arenig) of Bohemia (Paris & Mergl, 1984), the Solimões Basin, Benjamin Constant Formation (Middle Arenig-Lower Llanvirn) of Brazil (Grahn, 1992), the Levis Formation Zone A (Lower Arenig) of Québec, Canada (Achab, 1980), and from the

Cow Head Group (Arenig), Cow Head peninsula, western Newfoundland, Canada (Achab 1986a).

Conochitina dolosa (Laufeld 1967)

Plate 1, figs. 14-17

Conochitina dolosa Laufeld, 1967, p. 302, fig. 11; Achab, 1977b, p. 2198, pl. 5, figs. 3, 4, 9, 10.

Conochitina cf. *dolosa* Paris, in Henry *et al.*, 1974, p. 312, pl. 1, figs. 16, 19, pl. 2, fig. 10, pl. 4, fig. 6, pl. 5, figs. 5, 6; Paris, 1981, p. 180, pl. 15, fig. 21, pl. 38, fig. 3.

Conochitina aff. *C. dolosa* Melchin, 1982, p. 186, pl. 6, figs. 6, 9; Grahn & Nøhr-Hansen, 1989, p. 37, fig. 3C.

Description. Elongate, conical shaped vesicle with maximum diameter at the basal margin. Flanks straight, tapering slightly but uniformly towards the aperture. Neck and chamber indistinguishable, shoulders and flexure absent. Collarette straight and indistinct, aperture entire. Basal margin inconspicuous to well rounded, base hemispherical to convex. Smooth wall lacks ornament.

Dimensions.

Overall length:	793 (824) 840 μm
Overall width:	143 (159) 172 μm
Oral tube length:	--
Neck width:	--
Aperture width:	94 (97) 103 μm

specimens measured: 15

Remarks. *Conochitina dolosa* (Laufeld, 1967) has not previously been described from Lower Ordovician (Arenig) strata. Specimens within this study are consistent with Laufeld's (1967) original diagnosis, though they do not show the remnants of a basal mucron which he suggests is sometimes present. *C. dolosa* is quite distinct from other large conochitinids, particularly *C. minnesotensis*, which has a greater total length and is typically flared at the aperture, and from large rhabdochitinid species which are mostly cylindrical and typically have a flattened base. *Conochitina dolosa* bears a tenuous resemblance to *C. kryos*, *C. poumoti* and *C. langei*. However, *C. kryos* is smaller and much narrower, *C. poumoti* possesses a short weakly defined neck, and *C. langei* is distinctly swollen aborally. As with the majority of conochitinid species, chains have not been recorded.

Occurrence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; (SPI 78), *L. v. maximus* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. *Conochitina dolosa* has traditionally been reported from Upper Ordovician strata, but will herein include Arenigian strata. Since Laufeld (1967) first named and described the species from the Lower Dalby Formation (Lower Caradoc) of Fjäcka, Dalarna, Sweden, it has been recovered from the Base of Louredo Formation (Llandeilo), Buçaco syncline, Portugal (Paris, 1981), and from the Troedsson Cliff Member (Middle

Ashgill) of North Greenland (Grahn & Nøhr-Hansen, 1989). North American occurrences were restricted to the Vaureal Formation, *Climacograptus prominens elongatus* Zone (Middle Ashgill) of Anticosti Island, Quebec, Canada (Achab, 1977b), the Upper Lindsay and lowest Whitby [uppermost Edenian? to lowest Maysvillian (upper Caradoc)], Simcoe Group, southern Ontario, Canada (Melchin, 1982), and the Lower Athens Shale (Llanvirn-Llandeilo) of Pratt Ferry, Alabama, U.S.A. (Grahn & Bergström, 1984). *Conochitina* cf. *dolosa* specimens were also recovered by Paris (1981) from the Cacemes Formation (lower Llanvirn-lower Caradoc), Buçaco syncline, Portugal and from the Kermeur Formation (lower Caradoc), Chateaulin syncline, Massif Armoricain.

Conochitina sp. cf. ***C. dolosa***

Plate 1, fig. 26.

Description. Vesicle elongate and conical in shape with maximum diameter slightly (ca 20% of the length) above the basal margin. Flanks largely straight, slightly irregular, and taper slightly towards the aperture. Neck and chamber indistinguishable, shoulders and flexure absent. Collarette straight and indistinct, aperture entire. Basal margin inconspicuous and base ogival. Smooth wall.

Dimensions.

Overall length:	798 μm
Overall width:	167 μm
Oral tube length:	--
Neck width:	--

Aperture width:	99 μm
# specimens measured:	1

Remarks. Though the dimensions and overall shape of *Conochitina* sp. cf. *C. dolosa* are consistent with individuals identified as *C. dolosa* (Laufeld, 1967) within this study, its tapered base and slightly irregular flanks questions the certainty of a specific designation.

Occurrence. Arenig: Western Brook South (WBS 34), *I. v. maximus* Zone.

Conochitina sp. cf. ***C. elegans*** (Eisenack 1931)

Plate 1, fig. 13; Plate 7, fig. 2.

Description. Large tubular, subcylindrical or weakly conical vesicle with indistinguishable neck and chamber. Collarette straight and indistinct, flexure and shoulders absent. Flanks straight and slightly wider at the base. Basal margin rounded and distinctly swollen, forming the widest portion of the vesicle, just anterior of which lies a noticeable but minor constriction. Base flat to concave. Wall smooth.

Dimensions.

Overall length:	744 (827) 900 μm
Overall width:	151 (183) 200 μm
Oral tube length:	--
Neck width:	100 (109) 121 μm
Aperture width:	128 (142) 157 μm
# specimens measured:	5

Remarks. *Conochitina elegans* (Eisenack, 1931) is previously undescribed from the Lower

Ordovician (Arenig); prior reports by Jenkins (1967, 1969, 1970a), Eisenack (1968, 1976b) and Gao (1968) show this large conochitind is confined mainly to the Upper Ordovician (Caradoc). Specimens identified as *Conochitina* sp. cf. *C. elegans* within this study are approximately twice as large as those Eisenack (1931) first named and described from the Baltic. However, Jenkins (1967) recorded large forms from the Caradoc of Shropshire which were only slightly smaller than material from western Newfoundland. Its swollen basal margin and slightly concave base makes *C. elegans* distinctive when compared to other large conochitinids. Its close resemblance to *Rhabdochitina concephala* (Eisenack, 1934) prompted Eisenack (1959) to unite the two as one species. Later, while working with British type material, Jenkins (1967) confirmed the validity of this assignment.

Occurrence. Arenig: Cow Head North (CHN 9.6-B/C), *T. approximatus* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Conochitina homoclaviformis (Taugourdeau 1961)

Plate 1, figs. 18-23.

Rhabdochitina claviformis Taugourdeau, 1961, p. 150, pl. 4, figs. 69, 70.

Conochitina homoclaviformis Bouché, 1965, p. 156, pl. 1, figs. 13, 14; Paris, 1979, p. 31, pl. 3, figs. 4, 5, 9; Paris, 1981, p. 182, pl. 17, fig. 19, pl. 18, figs. 13, 14, 19.

Clavachitina claviformis Rauscher & Doubinger, 1967a, p. 311, pl. 2, fig. 1.

?*Clavachitina* cf. *dactylus* Rauscher & Doubinger, 1967a, p. 315, pl. 2, fig. 2.

?*Clavachitina decipiens* Rauscher & Doubinger, 1967a, p. 315, pl. 2, fig. 3.

?*Eremochitina brevis conica* Rauscher & Doubinger, 1967a, p. 316, pl. 3, fig. 11.

Lagenochitina claviformis Rauscher & Doubinger, 1967a, p. 316, pl. 4, figs. 9?, 10.

Lagenochitina porrecta Umnova, 1969, p. 332, pl. 2, figs. 11, 12.

Non: *Conochitina claviformis* Eisenack, 1931, p. 84, pl. 1, fig. 17.

Description. Conical shaped vesicle with neck and chamber merging imperceptibly. Oral tube subcylindrical to weakly conical with the neck slightly narrower than the aperture; neck approximately 30 to 40 % of the maximum width. Aperture entire, collarette slightly flared. Basal margin rounded and base convex to slightly rounded. In rare cases where individuals have been compacted along the longitudinal axis, the base appears slightly concave and a weakly defined flexure can be seen. Maximum width typically occurs at the basal margin. Vesicle wall is smooth.

Dimensions.

Overall length:	537 (762) 828 μm
Overall width:	162 (188) 207 μm
Oral tube length:	–
Neck width:	103 (119) 138 μm
Aperture width:	99 (124) 143 μm
# specimens measured:	15

Remarks. Bouché (1965) designated the name *C. homoclaviformis* as a replacement name (*nomen novum*) for Taugourdeau's (1961) *Rhabdochitina claviformis*, which, when transferred to *Conochitina*, would be a junior homonym of *C. claviformis* (Eisenack, 1931).

It is distinguished from the latter by its smooth test wall and lack of a well-defined basal mucron. Western Newfoundland specimens are larger than either Eisenack's, Bouché's, or Paris' (1979, 1981), but are consistent with the basic form and length to width ratios of approximately 3.5-4:1. Bouché recorded *C. homoclaviformis* from the upper Ordovician (likely Llandeilo) and Paris (1979, 1981) recorded it from the Caradoc. Umnova's illustration of *L. porrecta* (1969), which she recorded from the Lower Llanvirn of the Russian Platform (Kunda Horizon), looks remarkably like my specimens of *C. homoclaviformis* in form and size. While individuals of *C. homoclaviformis* within this study are confidently assigned to this species, it has not been previously documented from Lower Ordovician (Arenig) type sections.

Occurrence. Arenig: Cow Head South (CHS 11.30), *I. v. lunatus* Zone; Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone.

Stratigraphic Distribution. The type material of the species was recovered by Bouché (1965) from the Upper Ordovician (Sahara Zone 2) of Aquitaine, North Africa. Prior to its formal name change, Taugourdeau (1961) reported the species from the Upper Ordovician (Caradoc?) of Europe, which was later confirmed by Rauscher & Doubinger (1967). Paris (1979) recovered several well preserved individuals from the Louredo Formation (Llandeilo), Buçaco syncline, Portugal, and several years later, he described individuals from the upper part of the Louredo Formation (Caradoc) in Portugal. *Conochitina homoclaviformis* has also

been observed in Spain, from the "Pizarras intermedias" Formation (Caradoc), Monts de Tolède (Paris *in* Robardet *et al.* 1980), and in the Upper Ordovician of the Valle syncline in the Province of Séville (Paris, 1981).

Conochitina kryos (Bockelie 1980)

Plate 1, figs. 24, 25.

Conochitina kryos Bockelie, 1980, p. 10, pl. 1, figs. 1, 9, 10, 12, 14, 15, 20; Achab, 1986a, p. 689, pl. 1, figs. 4, 5, pl. 3, figs. 5-8.

Conochitina cf. *C. kryos* Achab, 1982, p. 1300, pl. 2, figs. 4-7.

Description. Elongate cylindroconical shaped vesicle with maximum diameter at the basal margin. "Neck" and "chamber" indistinguishable; collarette straight and indistinct, may be very slightly flared. Flanks straight and taper slightly but consistently towards the aperture. Basal margin inconspicuous and base hemispherical to convex. Vesicle surface lacks ornament but appears to possess a granular pattern.

Dimensions.

Overall length:	724 (754) 769 µm
Overall width:	123 (129) 138 µm
Oral tube length:	--
Neck width:	--
Aperture width:	79 (82) 86 µm
# specimens measured:	5

Remarks. *Conochitina kryos* resembles many other elongate cylindroconical conochitinids,

particularly *C. poumoti*, *C. minnesotensis*, *C. dolosa*, and even *Rhabdochitina tubularis*. It is distinguished from *C. minnesotensis* on its smaller size and straight flanks that taper consistently from base to aperture, and the lack of a distinctly flared collarette. *Conochitina poumoti* has a short, weakly defined cylindrical neck in the first 25-35% of its total length and its flanks are typically convex in the lower half of the vesicle, while *C. dolosa* is wider and more robust; *Rhabdochitina tubularis* has an almost uniform width along its entire length. Bockelie (1980) indicated that the presence of a reticulated surface is characteristic of the species, which deviates from the generic diagnosis. The presence of a granular texture on the surface of present specimens suggests that Bockelie may have originally observed mineral deformation (e.g. overprint) rather than true morphological variability.

Occurrence. Arenig: Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 52-A), *U. austrodentatus* Zone.

Stratigraphic Distribution. In North America, samples of the species have only been reported from Zones C and D (Upper Arenig) of the Levis Formation, Quebec, Canada (Achab, 1982, 1986a). In Europe, its occurrence is restricted to the *l.v. victoriae* Zone (late Arenig-early Llanvirn) of the Valhallfonna Formation, Ny Friesland, Spitsbergen (Bockelie, 1980).

Conochitina langei (Combaz & Péniguel 1972)

Plate 1, figs. 27-37; Plate 7, figs. 7, 12.

Conochitina langei Combaz & Péniguel, 1972, p. 138, pl. 3, fig. 12, pl. 4, fig. 6.

Fustichitina langei Achab, 1982, p. 1229, pl. 1, figs. 1-5; Achab, 1983, p. 925, pl. 2, figs. 12-14; Achab, 1986a, p. 693, pl. 4, figs. 11-14.

Description. Fungiform shaped vesicle with neck and chamber merging imperceptibly. Short, cylindrical to weakly conical oral tube makes up approximately 25-30% the total length. Collarette straight and indistinct. Flexure and shoulders absent. Flanks straight to weakly concave, widening towards the base with maximum diameter just above the basal margin, giving the chamber a slightly swollen appearance. Basal margin inconspicuous and base hemispherical; in several individuals the base may appear more bluntly ogival, but rarely convex and never possessing a mucron. Wall smooth.

Dimensions.

Overall length:	537 (659) 794 μm
Overall width:	150 (176) 212 μm
Oral tube length:	--
Neck width:	--
Aperture width:	91 (116) 123 μm
# specimens measured:	30

Remarks. *Conochitina langei* (Combaz & Péniguel, 1972) is quite distinct and rarely confused with other species. Its large club shape and smooth test wall distinguishes it from elongate forms of *Lagenochitina esthonica* (Eisenack, 1955b) which has a flared collarette

and distinct flexure and shoulders, and from ornamented [spinose] forms of *Belonechitina pirum* (Achab, 1982). Specimens recovered from Cow Head, western Newfoundland are consistent with Combaz & Péniguel's (1972) original illustrations and descriptions of their type material from Australia, and very similar to Achab's Levis Formation material (1983, 1986a). Though morphological variation within *C. langei* has not been as well documented as with other species, Achab (1982) illustrated several forms that resembled elongated lagenochitinids (possibly *L. esthonica* or *L. maxima*).

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone; (WBS 34), *I. v. maximus* Zone; (WBS 52-A), *U. austrodentatus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. *Conochitina langei* was originally described by Combaz & Péniguel (1972) from the Nambeet and Thangoo formations, Zones 0_2 and 0_3 (Arenig) of the Canning Basin, Australia, and subsequently reported by Achab (1983) from the Table Head Formation, *D. decoratus* Zone (Llanvirn) of western Newfoundland, Canada, and the Levis Formation, *D. bifidus* (C) and *G. dentatus* (D) zones (Upper Arenig) of Quebec (Achab, 1982, 1986a).

Conochitina sp. cf. ***C. langei*** (Combaz & Péniguel 1972)

Plate 3, figs. 25-29.

Description. Ovoid shaped vesicle with a short cylindrical oral tube, approximately 25 to 30% of the total length, and straight indistinct collarette. Shoulders absent, flexure very weak. Flanks straight and widen consistently toward the base with maximum diameter just below the vesicle's midpoint. Basal margin inconspicuous and base hemispherical. Wall smooth.

Dimensions.

Overall length:	384 (423) 483 µm
Overall width:	172 (185) 197 µm
Oral tube length:	--
Neck width:	108 (114) 118 µm
Aperture width:	108 (112) 118 µm
# specimens measured:	5

Remarks. *Conochitina* sp. cf. *C. langei* shares features with the holotype of *C. langei*, however, its slightly distorted shape (e.g. straight neck region and broader base) does not permit a certain specific assignment.

Occurrence. Arenig: St. Paul's Inlet (SPI 78), *I. v. maximus* Zone; Western Brook South (WBS 34), *I. v. maximus* Zone.

Conochitina minnesotensis (Stauffer 1933)

Plate 2, figs. 1-8; Plate 7, figs. 10, 11.

Rhabdochitina minnesotensis Stauffer, 1933, p. 1209, pl. 60, fig. 39 (holotype); Eisenack, 1939, p. 146, pl. B, fig. 13; Collinson & Schwalb, 1955, p. 30, fig. 10.

Rhabdochitina cf. *minnesotensis* Taugourdeau & DeJekhowsky, 1960, p. 1230, pl. 10, fig. 134.

Conochitina minnesotensis Eisenack, 1962b, p. 353, text-figs. 1-6; Eisenack, 1965, p. 126, pl. 10, figs. 7, 8; Laufeld, 1967, p. 306, fig. 13; Evitt, 1969, fig. 18-12 a; Jenkins, 1969, p. 17, pl. 3, figs. 11-22, pl. 4, figs. 1-5, pl. 5, figs. 1-5, 15; Jenkins, 1970b, pl. 2, figs. 20-27; Combaz & Péniguel, 1972, p. 140, pl. 3, fig. 13; Männil, 1972, p. 570; Martin, 1975, p. 1009, pl. 2, fig. 9; Grahn, 1980, p. 20, fig. 12 A-D; Nõlvak, 1980, pl. 30, fig. 3; Grahn, 1981a, p. 25, fig. 9 A; Grahn, 1981b, p. 11, fig. 4 A-D; Grahn, 1982a, p. 27, fig. 12 M, N; Melchin, 1982, p. 189, pl. 7, figs. 1, 7; Achab, 1983, p. 930, pl. 4, figs. 1-4; Martin, 1983, p. 13, pl. 3, figs. 16, 20; Grahn, 1984, p. 15, pl. I, fig. Q; Grahn & Bergstrom, 1984, p. 112, pl. 1, fig. M; Bergstrom & Grahn, 1985, pl. 1, fig. M; Grahn & Miller, 1986, fig. 6, nos. 8, 9.

?*Rhabdochitina* cf. *R. minnesotensis* Whittington, 1955, p. 850, pl. 83, figs. 3, 6.

?*Rhabdochitina usitata* Martin, 1978, p. 80, pl. 12.1, figs. 2, 4 (non figs. 1, 9, 15, 18).

Description. Large conical to subcylindrical vesicle with neck and chamber merging imperceptibly. Orally, the vesicle flares slightly so that the collarette is slightly wider than

the neck; aperture straight. Flanks are largely straight but curve slightly towards the aboral pole where they widen to maximum diameter just above an inconspicuous basal margin; base hemispherical. Often the base possesses a blunt but distinct mucron (up to 20 μm wide and 14 μm high) at its centre which gives the base an almost pointed, nipple-like appearance. Wall smooth.

Dimensions.

Overall length:	783 (921) 1089 μm
Overall width:	110 (176) 192 μm
Oral tube length:	–
Neck width:	89 (92) 96 μm
Aperture width:	98 (103) 109 μm
# specimens measured:	25

Remarks. Jenkins' (1969) illustrations of *Conochitina minnesotensis* showed the variation in morphology of the base and basal process. Though typical individuals possess a distinct basal process or mucron, it is not uncommon for it to be lost or flattened during preservation, or absent altogether. Stauffer's (1933) original discussion of the species even mentioned the lack of a basal mucron in specimens from the type locality.

Conochitina minnesotensis is currently the largest described Ordovician conochitinid; Eisenack (1965) recorded individuals up to 2000 μm from the Baltic region. Western Newfoundland specimens fall within the typical size range for the species (700-1500 μm), leaving little doubt as to their identity. Though the species is quite distinct, *C. minnesotensis* can be mistaken for other large conochitinids, particularly *C. dolosa,* which falls within the range of variability of *C. minnesotensis*. Miller (1976) suggested that the two species are

conspecific because of their affinity for the same type of stratum, and Melchin (1982) suggested that *C. minnesotensis* grades morphologically into *C. dolosa*. While there does appear to be a close biological relationship between *C. minnesotensis* and *C. dolosa*, they are currently recognized as two separate and distinct taxa.

Occurrence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone; Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; Western Brook South (WBS 28-A), *I. v. lunatus* Zone; (WBS 34), *I. v. maximus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. *Conochitina minnesotensis* was first described by Stauffer (1933) from the Middle Ordovician Decorah Formation (lower Caradoc) of southern Minnesota, U.S.A. Decades later, Whittington (1955) and Jenkins (1969) both reported large populations from the upper Viola Formation (upper Caradoc-lower Ashgill) of Oklahoma. Other North American reports of the species have come from the Utica Formation (Caradoc) of Montmorency Falls, Quebec, Canada (Martin, 1975), the Kope Formation (Upper Caradoc) at Maysville, Kentucky (Miller, 1976), the uppermost Gull River to uppermost Lindsay [upper Blackriveran to lowest Maysvillian (Caradoc)] of the Simcoe Group, southern Ontario, Canada (Melchin, 1982), the Table Head Formation (Llanvirn) of Newfoundland, Canada (Achab, 1983), the Leray, Montréal, Neuville and Lotbinère formations (middle to upper Caradoc) within the Saint Lawrence Platform of Quebec and southeastern Ontario (Martin, 1983), and the Lenoir Limestone (Llanvirn-Llandeilo) at Pratt

Ferry and Marble Hollow, Alabama, U.S.A. (Grahn & Bergström, 1984). Numerous well preserved examples of the species [*Rhabdochitina* cf. *minnesotensis*] have even been recovered from Zone 3 (Silurian) of the Sahara, south of Algeria (Taugourdeau & DeJekhowsky, 1960), and from the Nambeet to Goldwyer formations, Zones 0_2 to 0_5 (Arenig-Llandeilo) of the Canning Basin, Australia (Combaz & Péniguel, 1972).

In the Baltic region *C. minnesotensis* has been reported from the Herscheider Shale (Caradoc?) of Westphalia, West Germany (Eisenack, 1939), the Volkov (B_2-lower to upper Arenig) to the Porkuni Stage (F_2-upper Ashgill) (Eisenack, 1962b, 1965, 1968; Nõlvak, 1980) and from the "Ostseekalk" of Estonia (Eisenack, 1965), the Upper Dalby and Skagen Limestones (lower and middle Caradoc) of Dalarna, Sweden (Laufeld, 1967), and the eastern Baltic region (Mannil, 1972). Grahn (1980, 1981a) also reported the species from the Upper Langevojan to Lower Valastean (upper Arenig-lower Llanvirn) and Persnäs (lower Llandeilo) to Lower Dalby Limestones of Öland, and the Lower Dalby to Bestorp (Lower Ashgill) Limestones of Västergötland, Sweden (Grahn, 1981b). In Gotland, he described individuals from the Idaverean to Pirguan/Jonstorp (lower Caradoc-middle Ashgill) (Grahn, 1982a), and from Baltic erratics of the Lower *Macrourus* Siltstone (Grahn, 1981a).

Conochitina ordinaria (Achab 1980)

Plate 2, figs. 13-15.

?*Conochitina communis* Umnova, 1969, pl. 1, fig. 22.

Conochitina ordinaria Achab, 1980, p. 228, pl. 1, figs. 1-6; Playford & Miller, 1988, p. 22,

pl. 2, figs. 1-4, pl. 4, figs. 9, 10.

Conochitina cf. *C. ordinaria* Achab, 1982, p. 1304, pl. 4, figs. 1, 5, 6.

?*Conochitina* sp. 2 Elaouad-Debbaj, 1984, p. 73, pl. 2, fig. 3.

Description. Short conical to cylindroconical vesicle. Weakly conical neck merges with the chamber imperceptibly and tapers slightly towards the aperture. Collarette typically indistinct but may flare very slightly. Flanks convex and widen at the lower portion of the chamber with maximum diameter typically just above a slightly rounded basal margin. Base generally flattened, though individuals with more convex bases are not uncommon. Wall smooth.

Dimensions.

Overall length:	390 (393) 394 μm
Overall width:	123 (135) 143 μm
Oral tube length:	--
Neck width:	--
Aperture width:	96 (101) 105 μm
# specimens measured:	7

Remarks. Specimens of *Conochitina ordinaria* within this study fall within the range of size and variability of Achab's (1980) type material from the lower part of the Levis Formation (Arenig), Quebec, Canada, and are consistent with those identified by Playford & Miller (1988) from the Georgina Basin (Arenig), Queensland, Australia. However, specimens from the upper part of the Levis Formation were generally more conical than those from the lower section and those from the Georgina Basin. While *C. ordinaria* resembles *C. decipiens* (Taugourdeau & DeJekhowsky, 1960), Achab (1980) noted that *C.*

ordinaria is shorter, its neck is straighter and its chamber is smaller, whereas the base of *C. decipiens* is usually concave. Umnova (1969, pl. 1, fig. 22) and Elaouad-Debbaj (1984, p. 73; pl. 2, fig. 3) both illustrated and described Arenig conochitinids, *C. communis* and *Conochitina* sp. 2, respectively, which have silhouettes resembling the holotype of *C. ordinaria*, suggesting that they may be conspecific. While Umnova's illustration of *C. communis* resembles *C. ordinaria*, it does not bear a close resemblance to Taugourdeau's (1961) holotype of *C. communis* from Aquitaine.

Occurrence. Arenig: Cow Head South (CHS 11.30), *I. v. lunatus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone; (WBS 52-A), *U. austrodentatus*; (WBS 62), *U. austrodentatus*.

Stratigraphic Distribution. *Conochitina ordinaria* was originally recovered by Achab (1980, 1982) from the Levis Formation (Lower Arenig-Upper Arenig) of Quebec, Canada, with subsequent reports of its occurrence from the Coolibah and Nora Formations (middle-late Arenig) of the Georgina Basin, Queensland, Australia (Playford & Miller, 1988) and possibly from similar aged Moroccan strata (Elaouad-Debbaj, 1984).

Conochitina pervulgata (Umnova 1969)

Plate 2, figs. 26-31; Plate 7, figs. 3-5.

Lagenochitina pervulgata Umnova, 1969, p. 55, pl. 2, figs. 13, 14; Umnova, 1976, pl. 1, figs. 7, 8.

Fustichitina pervulgata Achab, 1980, p. 231, p. 2, figs. 6-9.

Fustichitina cf. *pervulgata* Achab, 1982, p. 1304, pl. 4, figs. 4, 8, 11, 12; Achab, 1986a, p. 693, pl. 4, figs. 6-9.

Concchitina pervulgata Paris & Mergl, 1984, p. 49; Playford & Miller, 1988, p. 23, pl. 2, figs. 6-10, pl. 4, figs. 13, 14; Grahn, 1992, p. 714, fig. 8, nos. 1, 2.

Description. Conical to subcylindrical vesicle, slightly wider or swollen towards its base, with the oral tube and chamber merging imperceptibly. Orally the vesicle tapers slightly into a subconical to cylindrical "neck" which may flare very slightly at the aperture. Collarette indistinct. Basal margin inconspicuous to well rounded and merges into weakly convex flanks. Base generally hemispherical but can be distorted by compression. Wall smooth.

Dimensions.

Overall length:	436 (549) 616 μm
Overall width:	99 (122) 138 μm
Oral tube length:	--
Neck width:	--
Aperture width:	79 (92) 108 μm
# specimens measured:	15

Remarks. *Conochitina pervulgata* (Umnova, 1969) is a relatively simple, undifferentiated conochitinid species that resembles other members of the genus, particularly *C. poumoti* (Combaz & Péniguel, 1972). It can, however, be distinguished by its base, which overall is more consistently rounded to convex while the base of *C. poumoti* is typically more flattened. The original description of *C. poumoti* given by Combaz & Péniguel also shows

the presence of a weakly defined flexure at about one quarter to one fifth the total length which separates the lower vesicle from a short, subcylindrical "neck". The original size diagnosis of *C. pervulgata* is 450 to 650 μm in length. Western Newfoundland specimens of *C. pervulgata* range in size from 436 to 616 μm in length, slightly outside the range of specimens (336 to 555 μm) from the Georgina Basin (Playford & Miller 1988), but otherwise consistent with those Achab (1980) recovered (400 to 650 μm) from the lower Arenig Levis Formation of Quebec.

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; Cow Head South (CHS 11.30), *I. v. lunatus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone; (WBS 34), *I. v. maximus* Zone; (WBS 52-A), *U. austrodentatus* Zone.

Stratigraphic Distribution. Umnova (1969) reported the type species from the northern part of the Russian Platform within the Volkhovian and Kundan horizons (uppermost Arenig-lower Llanvirn). Playford & Miller (1988) recovered the species from the Coolibah and Nora Formations (middle-late Arenig) of the Georgina Basin, Queensland, Australia, and later it was recovered from the Solimões Basin, Benjamin Constant Formation (Middle Arenig-Lower Llanvirn) of Brazil (Grahn, 1992). North American reports appear to be restricted to Quebec and Newfoundland, Canada, where the species has been recovered from the Levis Formation, Zones A to D (lower Arenig-upper Arenig) (Achab, 1980, 1982,

1986a), and the Cow Head Group (Arenig), (Achab, 1980, 1986a), respectively.

Conochitina poumoti (Combaz & Péniguel 1972)

Plate 2, figs. 16-22; Plate 7, figs. 8, 15.

Rhabdochitina sp. Echols & Levin, 1966, pl. 2, fig. 1 (non fig. 2).

Conochitina poumoti Combaz & Péniguel, 1972, p. 140, pl. 4, figs. 3-5, 10; Bockelie, 1980, p.11; pl. 1, figs. 3, 4, 16, 23; Achab, 1982, p. 1302, pl. 1, figs. 6-11; Achab, 1983, p. 930, pl. 4, figs. 5-13; Achab, 1986a, p. 689, pl. 1, figs. 1-3; Elaouad-Debbaj, 1988, p. 91, pl. 7, figs. 3, 14.

?*Rhabdochitina* cf. *magna* Neville, 1974, p. 201, pl. 6, figs. 10, 13, 15 (non figs. 7-12, 14, 16, 17).

Description. Subcylindrical to weakly conical shaped vesicle. Short, subcylindrical neck makes up approximately 15-20% the vesicle's total length which flares very slightly, almost imperceptibly towards the aperture making the neck narrower than the collarette. Shoulders absent, flexure very weak at the junction of the neck and chamber. Flanks straight to slightly curved, but just above the basal margin they narrow slightly towards the base. Basal margin blunt or slightly rounded, but depending upon preservation, can be largely inconspicuous. Base flat to convex, but in rare specimens it can appear more rounded or even hemispherical. Smooth test wall.

Dimensions.

Overall length:	581 (634) 850 μm
Overall width:	115 (125) 178 μm
Oral tube length:	--
Neck width:	--
Aperture width:	91 (104) 123 μm
# specimens measured:	20

Remarks. Present specimens of *Conochitina poumoti* are comparable to Combaz & Péniguel's (1972) original diagnosis, only slightly larger, and consistent with those illustrated by Achab (1982, 1983, 1986a). The presence of a short, cylindrical neck which merges almost imperceptibly with the chamber, and the smooth test wall separate this species from other similar conochitinids (e.g. *C. kryos, C. pervulgata*). Bockelie (1980) suggested the species may sometimes possess a basal callus (=mucron). However, Combaz & Péniguel (1972) did not report the presence of a basal callus on the holotype so it is not presently considered a valid feature taxonomically. Individuals identified here as *C. poumoti* show such considerable resemblance to Neville's (1974) *Rhabdochitina magna* (pl. 6, figs. 10, 13, 14) that they are likely conspecific.

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 28-A), *I. v. lunatus* Zone; (WBS 62), *U. austrodentatus* Zone.

StratigraphicDistribution. Combaz& Péniguel (1972) first recovered abundant specimens

of *Conochitina poumoti* from Zones 0_3 and 0_4 (Arenig-Llanvirn) of the Thangoo and Goldwyer formations, Canning Basin, Australia. Since then the species has been found within the Lower part of the Valhallfonna Formation, *D. protobifidus* Zone (late Arenig-early Llanvirn) of Ny Friesland, Spitsbergen (Bockelie, 1980), the Lower Fezouata Formation (Tremadoc) of the Anti-Atlas, Morocco (Elaouad-Debbaj, 1988), the Table Head Formation, *D. decoratus* Zone (Llanvirn) of western Newfoundland (Achab, 1983) and the Levis Formation, Zones C and D (upper Arenig) of Quebec (Achab, 1982, 1986a).

Conochitina sp. cf. ***C. poumoti*** (Combaz & Péniguel 1972)

Plate 2, figs. 23-25.

Description. Conical shaped vesicle with short, cylindrical neck, about one quarter to one fifth the total length, and straight collarette which is slightly wider than the neck. Shoulders absent, flexure extremely weak. Flanks slightly curved (convex) with maximum diameter about one third the vesicle length from the base. Basal margin well rounded to inconspicuous and base convex to rounded. Wall smooth without ornament.

Dimensions.

Overall length:	636 (682) 739 µm
Overall width:	172 (183) 187 µm
Oral tube length:	--
Neck width:	--
Aperture width:	95 (107) 113 µm
# specimens measured:	5

Remarks. While *Conochitina* sp. cf. *C. poumoti* resembles Combaz & Péniguel's (1972) holotype, its swollen elongated ovoid "chamber" (e.g. convex flanks) and hemispherical base precludes its strict assignment to the species.

Occurrence. Arenig: St. Paul's Inlet (SPI 78), *I. v. maximus* Zone; Western Brook South (WBS 62), *U. austrodentatus* Zone.

Conochitina raymondi (Achab 1980)

Plate 3, figs. 1-5; Plate 7, fig. 14

Conochitina raymondi Achab, 1980, p. 224, pl. 2, figs. 1-5; Achab, 1986a, p. 691, pl. 2, figs. 4-6, pl. 3, figs. 9-12.

Description. Conical shaped vesicle with subcylindrical oral tube that tapers slightly towards the aperture; collarette straight and indistinct. Neck and chamber indistinguishable, flexure and shoulders absent. Flanks straight to slightly convex and widen from the vesicle's midpoint to its maximum diameter just above the basal margin in the last 20 to 25% of the vesicle's length; below this the flanks are slightly curved to straight and taper towards the base. Basal margin rounded and base flat to only very slightly convex; rarely concave. Wall smooth.

Dimensions.

Overall length:	532 (641) 737 μm

Overall width:	143 (168) 192 μm
Oral tube length:	--
Neck width:	--
Aperture width:	91 (109) 123 μm
# specimens measured:	15

Remark. *Conochitina raymondi* (Achab, 1980) resembles *C. ventriosa* and *C. grandicula* (=genus *Fustichitina*, Achab 1980), but can be distinguished by its flat base which can have a slight depression giving a concave appearance, and fairly straight lateral margin below the point of maximum width. Both *C. ventriosa* and *C. grandicula* have inconspicuous basal margins and hemispherical bases, and *C. grandicula* has a longer maximum length. In addition, though *C. raymondi* resembles *C. ordinaria*, it can be distinguished by its larger size, flat base and flanks which are straight below the maximum diameter; *C. ordinaria* is typically smaller and has a convex to slightly rounded base.

Occurrence. Arenig: St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 18-A), *T. akzharensis Zone*; (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 34), *I. v. maximus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. Levis Formation, Zones B and C (lower Arenig) of Quebec, (Achab, 1980, 1986a); Cow Head Group (Arenig) of western Newfoundland (Achab, 1980, 1986a).

Conochitina simplex (Eisenack 1931)

Plate 2, figs. 33-35.

Conochitina simplex Eisenack, 1931, p. 89, pl. 2, figs. 15, 16; Taugourdeau & DeJekhowsky, 1960, p. 1223, fig. 2; Benoit & Taugourdeau, 1961, p. 1405, text-fig. 2, pl. 2, figs. 17-21; Martin, 1969, p. 101, pl. 1, figs. 12, 16, 18.

Euconochitina simplex Rauscher, 1968, p. 54, pl. 3, figs, 4-6.

Conochitina aff. *simplex* Martin, 1975, p. 1011, pl. 1, fig. 9, pl. 3, fig. 3; Martin, 1983, p. 14, pl. 5, fig. 27.

?*Fustichitina* sp. Achab, 1986a, p. 694, pl. 2, figs. 14, 15.

?*Conochitina* sp. B Playford & Miller, 1988, p. 24, pl. 2, fig. 5.

Description. Small conical shaped vesicle with a very short, almost imperceptible, cylindrical oral tube. Collarette indistinct, flexure and shoulders absent. Flanks straight to slightly convex and widen towards the base. Basal margin rounded and base convex, hemispherical or ogival. Maximum diameter occurs just above the basal margin. Smooth test wall lacks ornament.

Dimensions.

Overall length:	248 (287) 350 µm
Overall width:	128 (136) 143 µm
Oral tube length:	--
Neck width:	--
Aperture width:	79 (83) 94 µm
# specimens measured:	10

Remarks. Eisenack (1931) appropriately named this small, very simple conochitinid which he recovered from Silurian rocks of the Baltic region. In his original diagnosis, the oral tube of *Conochitina simplex* is indistinct from the chamber and the base is either rounded or subogival to convex. Taugourdeau & DeJekhowsky (1960), Benoit & Taugourdeau (1961), Rauscher (1968) and Martin (1969) all recovered *C. simplex* from Arenig strata. Specimens illustrated by Achab (1986a: *Fustichitina* sp. p. 694; pl. 2, figs. 14, 15) and Playford & Miller (1988; *Conochitina* sp. B. pl. 2, fig. 5) from Arenig strata of the Cow Head Group, western Newfoundland and the Georgina Basin, Queensland, Australia, respectively, bear such close resemblance to my material, and that of previous authors, that they are most likely synonymous. Though *C. simplex* resembles *C. brevis* (Taugourdeau & DeJekhowsky, 1960) or *C. lagena* (Eisenack, 1968), it can be distinguished by its more slender, elongate form which has a distinctly rounded to almost ovoid shaped base and tapers more consistently towards the aperture.

Occurrence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone; Cow Head South (CHS 11.30), *I. v. lunatus* Zone; (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; (SPI 78), *I. v. maximus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone; (WBS 34), *I. v. maximus* Zone; (WBS 52-A), *U. austrodentatus* Zone.

Stratigraphic Distribution. Lower-Middle Arenig of Montagnes Noire, France (Rauscher,

1968); Utica Formation (Caradoc) of Montmorency Falls, Quebec, Canada (Martin, 1975); upper Arenig (Huy-4) of Condroz, Belgium (Martin, 1969); Silurian of Aquitaine (Taugourdeau, 1961); Nambeet to Goldwyer formations, Zone 0_2 to 0_5 (lower Arenig-Llandeilo) of the Canning Basin, Australia (Combaz & Péniguel, 1972); Ordovician-Gotlandien (Zones 1 to 3) of the Sahara, south of Algeria (Taugourdeau & DeJekhowsky, 1960; Benoit & Taugourdeau, 1961).

Conochitina subcylindrica (Combaz & Péniguel 1972)

Plate 2, fig. 32.

Conochitina subcylindrica Combaz & Péniguel, 1972, p. 141, pl. 3, figs. 8, 9; Achab, 1983, p. 924, pl. 1, figs. 6, 6a.

Description. Conical shaped vesicle which tapers slightly towards the aperture and widens at the base. Oral tube indistinct, collarette straight. Flanks are slightly curved with maximum diameter just above the basal margin. Basal margin rounded and base flat to convex. Vesicle wall smooth.

Dimensions.

Overall length:	398 (413) 424 µm
Overall width:	137 (144) 158 µm
Oral tube length:	--
Neck width:	--
Aperture width:	84 (87) 91 µm

specimens measured: 5

Remarks. This species very closely resembles the holotype and has not been previously described from the Arenig.

Occurrence. Arenig: Western Brook North (WBN 29), *D. bifidus*; Western Brook South (WBS 34), *I. v. maximus* Zone.

Stratigraphic Distribution. Goldwyer Formation (Llandeilo) of the Canning Basin, Australia; Table Head Formation (Llanvirn) of western Newfoundland, Canada (Achab, 1983).

Conochitina symmetrica (Taugourdeau & DeJekhowsky 1960)

Plate 2, figs. 11, 12.

Conochitina symmetrica Taugourdeau & DeJekhowsky, 1960, p. 1223, pl. 4, fig. 59; Benoit & Taugourdeau, 1961, fig. 2, pl. 2, figs. 17-21; Gao, 1968, pl. 2, figs. 7, 12; Achab, 1980, p. 226, pl. 3, figs. 7-10; Paris & Mergl, 1984, p. 50, pl. 4, fig. 8; Achab, 1986a, p. 691, pl. 3, figs. 1-4.

Euconochitina symmetrica Rauscher, 1968, p. 54, pl. 3, figs. 4-6.

?*Conochitina* Nautiyal, 1966, p. 316, pl. 28, figs. 27-30.

Description. Stout, conical shaped vesicle which tapers slightly towards the aperture and

may flare slightly at the collarette. Blunt basal margin flares out noticeably in the last (swollen) quarter of the vesicle's length and is wider than the collarette. Base rounded, convex or slightly flattened. Smooth vesicle wall lacks ornamentation.

Dimensions.

Overall length:	246 (267) 293 µm
Overall width:	145 (184) 217 µm
Oral tube length:	--
Neck width:	--
Aperture width:	109 (149) 178 µm
# specimens measured:	7

Remarks. An important diagnostic fossil for the *T. approximatus* Zone (Lower Arenig) of the Cow Head Group, western Newfoundand, *Conochitina symmetrica* closely resembles Eisenack's (1955b) *Eisenackitina oelandica* in form. However, *C. symmetrica* can be distinguished from *E. oelandica* by its larger overall dimensions and its lack of small spines covering the test wall. Achab (1980, 1986a) illustrated forms of *C. symmetrica* with a thin collarette that flares out sharply but slightly from the neck. Unfortunately, this feature can be easily lost either during preservation or processing and consequently, may not be found in all individuals.

Occurrence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone.

Stratigraphic Distribution. Ordovician (Zone 2) of the lower shale-sandstone complex of the Sahara (Taugourdeau & DeJekowsky, 1960; Benoit & Taugordeau, 1961); Zone 0_2

(Arenig) of the Canning Basin, Australia (Achab & Millepied, 1980); the Levis Formation, Zones A and C from the lowermost Arenig (*T. approximatus* Zone) of Quebec, Canada (Achab, 1980, 1986a); and the Lower Klabava Formation (Arenig) of Bohemia (Paris & Mergl, 1984).

Conochitina turgida (Jenkins 1967)

Plate 2, figs. 36-41; Plate 7, figs. 17, 18.

Rhabdochitina turgida Jenkins, 1967, p. 467, pl. 74, figs. 16-19; Jenkins, 1969, p. 29, pl. 9, figs. 10-12; Jenkins, 1970, pl. 4, fig. 21; Neville, 1974, p.202, pl. 7, figs. 1-11, 15; Martin, 1978, pl. 12.1, fig. 10; Martin, 1983, p. 19, pl. 5, fig. 36; Achab, 1986b, p. 289, pl. 2, figs. 9-11.

?*Conochitina* sp. Kauffman, 1971, p. 7, pl. 12, fig. 6.

Conochitina turgida Paris, 1996, p. 546.

Description. Subcylindrical to weakly conical vesicle lacking a well defined oral tube separate from the chamber. Flanks curved (convex) with maximum diameter typically at or just below the midpoint, from where the vesicle narrows slightly towards both the base and aperture. Collarette straight and indistinct. Basal margin blunt to slightly curved and base slightly convex, flat or even concave. Wall smooth.

Dimensions.

Overall length:	340 (389) 461 μm
Overall width:	153 (172) 187 μm
Oral tube length:	--
Neck width:	--
Aperture width:	94 (121) 140 μm
# specimens measured:	20

Remarks. Maximum diameter of *Conochitina turgida* (Jenkins, 1967) typically occurs between 40 to 60% the total length, though it is not uncommon for it to occur closer to the base. Neville recorded more variation in vesicle shape with the maximum diameter between 27 and 60% of the total length, and forms that ranged from slimmer to stouter than at present or those Jenkins (1967, 1969) identified. Several of Neville's specimens also possessed transverse thickenings similar to those Laufeld (1967) recorded on *C. tigrina*. This feature was not observed on any of the present material; Jenkins (pers. com. 1972, in Neville, 1974) considered this feature in the Newfoundland material to be preservational in nature and of no taxonomic value. Present specimens are slightly larger than Jenkins' original diagnosis, but are consistent with Neville's less restricted size ranges. Though *C. turgida* resembles short, wide examples of *R. striata* (Eisenack 1958), its lack of longitudinal striations distinguishes the two species. *Conochitina turgida* is previously been undescribed from Lower Ordovician (Arenig) strata.

Occurrence. Arenig: St. Paul's Inlet (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS

28-A), *I. v. lunatus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. Hope Shales, Weston Beds and Meadowtown Beds (Llanvirn-Llandeilo) of the Welsh Borderland, Shropshire, Great Britain (Jenkins, 1967); upper Viola Limestone (upper Caradoc-lower Ashgill) and Sylvan Shale (Caradoc-Ashgill) of Oklahoma, U.S.A. (Jenkins, 1969, 1970a); Table Head Formation (Caradoc) of the Port au Port Peninsula (Neville, 1974; Achab, 1983), and the middle Table Head Formation (Llanvirn) of western Newfoundland, Canada (Martin, 1978).

Conochitina ventriosa (Achab 1980)

Plate 3, figs. 6, 7.

?*Fustichitina grandicula* Achab, 1980, p. 231, pl. 4, figs. 1-3.

Fustichitina ventriosa Achab, 1980, p. 232, pl. 4, figs. 5-8.

Lagenochitina ventriosa Elaouad-Debbaj, 1988, p. 92, pl. 7, figs. 7-9, 13, 16.

Description. Short conical to ovoid shaped vesicle. Oral tube cylindrical to slightly tapering that merges almost imperceptibly into the chamber. Collarette straight and indistinct. Chamber is distinctly swollen and makes up the last 30 to 40% of the vesicle length with maximum diameter just above the basal margin. Basal margin inconspicuous, below which the flanks narrow and merge into a hemispherical to ogival base. Wall appears rough but lacks ornament.

Dimensions.

Overall length:	414 (521) 596 µm
Overall width:	140 (165) 182 µm
Oral tube length:	--
Neck width:	--
Aperture width:	86 (91) 98 µm
# specimens measured:	10

Remarks. Achab (1980) made the distinction between two species with cylindrical oral tubes and similarly swollen "chambers", *Fustichitina grandicula* and *F. ventriosa* (now included within *Conochitina*) on the basis of size, with *F. grandicula* being the more elongate of the two. Because subtle size differences are insufficient justification for dividing similar forms into separate taxa, these two species are likely conspecific and represent only one biological species. Similarities between *Conochitina ventriosa* and other lagenochitinid species with swollen or ovoid shaped chambers prompted Elaouad-Debbaj (1988) to place the species in the genus *Lagenochitina*. While *C. ventriosa* does possess certain features in common with some typical members of the genus *Lagenochitina*, the separation between neck and chamber does not appear distinctive enough to warrant its exclusion from the genus *Conochitina*. *Conochitina ventriosa* resembles *Lagenochitina destombesi* (Elaouad-Debbaj, 1988), but in the former the chamber is less swollen, typically only in the lower half of the vesicle, it has a less pronounced flexure, and no visible shoulders.

Occurrence. Arenig: Cow Head South (CHS 11.30), *I. v. lunatus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone.

Stratigraphic Distribution. Levis Formation (Lower Arenig) of Québec, Canada (Achab, 1980), and the Lower Fezouata Formation (Tremadoc) of the Anti-Atlas, Morocco (Elaouad-Debbaj, 1988).

Conochitina sp. **A**

Plate 3, fig. 8.

Description. Vesicle is conical in shape with indistinguishable neck and chamber. Orally, a small, very short weakly defined cylindrical neck can be seen which makes up only about 20% the total length. Basal margin blunt and base flat with maximum diameter just above the basal margin. Vesicle also appears to posses a small mucron or pore at the centre of the base approximately 19 μm wide. Region around aperture appears jagged, which may just be an artifact of preservation. Vesicle wall smooth.

Dimensions.

Overall length:	429 (438) 443 μm
Overall width:	167 (176) 187 μm
Oral tube length:	--
Neck width:	--
Aperture width:	109 (111) 112 μm
# specimens measured:	3

Remarks. While the shape of *Conochitina* sp. A resembles a flattened form of *C. subcylindrica*, the rarity of similar specimens does not permit a reliable identification.

Occurrence. Arenig: St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 29), *D. bifidus* Zone.

***Conochitina* sp. B**

Plate 3, fig. 9.

Description. Subcylindrical to weakly conical vesicle with straight flanks that are only very slightly curved, and taper slightly towards the aperture. Collarette may be slightly flared, but largely indistinct. Basal margin rounded and base flat. A short, blunt mucron projects aborally from the centre of the base. Vesicle wall smooth.

Dimensions.

Overall length:	535 μm
Overall width:	146 μm
Oral tube length:	--
Neck width:	--
Aperture width:	101 μm
# specimens measured:	1

Remarks. *Conochitina* sp. B resembles *C. tuba* (Eisenack, 1932) and *C. acuminata* (Eisenack, 1959) from the Silurian (Wenlock) of the Baltic. Although it is larger in size and its length to width ratio (3.6 to 1) falls just above the holotype (3.1 to 1), its older age (Arenig) suggests the species may not share a close affinity. Unfortunately, the rarity of specimens does not permit critical comparisons between taxa. While the silhouette of

Conochitina sp. B also resembles *C. subcylindrica* (Combaz & Poumot 1972), the presence of a small blunt mucron in *Conochitina* sp. B distinguishes the two species.

Occurrence. Arenig: Western Brook South (WBS 23-C), *D. bifidus* Zone.

Conochitina sp. C

Plate 3, figs. 10-12, 21.

Description. Conical to fungiform shaped vesicle with cylindrical oral tube that merges imperceptibly with the chamber. Collarette straight and indistinct, flexure and shoulders absent. "Chamber" is elongate and ovoid, with slightly curved (convex) flanks that are wider than the aperture. Maximum diameter occurs between the basal margin and the chamber midpoint with the vesicle tapering towards the base. Basal margin is inconspicuous and the base hemispherical to subogival. Wall smooth.

Dimensions.

Overall length:	673 (715) 737 µm
Overall width:	189 (191) 193 µm
Oral tube length:	277 (286) 293 µm
Neck width:	113 (119) 124 µm
Aperture width:	109 (112) 113 µm
# specimens measured:	5

Remarks. *Conochitina* sp. C closely resembles *Velatachitina veligera* (Poumot, 1968) from the Arenig of the Ed Gassi region of Algeria; however, it lacks a distinct translucent

periderm around the base which, although characteristic of the species, is rarely preserved.

Occurernce. Arenig: Western Brook South (WBS 23-C), *D. bifidus* Zone.

Conochitina sp. **D**

Plate 3, figs. 13-15.

Description. Subcylindrical to weakly conical shaped vesicle with short oral tube approximately one quarter the total length, and neck slightly narrower than the aperture. Collarette straight to only slightly flared, flexure and shoulders indistinct. Flanks slightly curved and widen to maximum diameter just below the "chamber" midpoint. Basal margin rounded and the base convex to weakly hemispherical. Wall smooth.

Dimensions.

Overall length:	631 (657) 670 µm
Overall width:	177 (181) 187 µm
Oral tube length:	--
Neck width:	--
Aperture width:	101 (108) 118 µm
# specimens measured:	4

Remarks. The shape of *Conochitina* sp. D is consistent with the form of the genus, and its partial resemblance to present forms of *C. homoclaviformis* suggests the two taxa may share an affinity. However, the slightly distorted shape and scarcity of specimens does not permit a specific identification.

Occurrence. Arenig: Cow Head South (CHS 11.30), *I. v. lunatus* Zone.

Conochitina sp. E

Plate 3, figs. 16, 17; Plate 7, figs. 6, 9.

Description. Conical shaped vesicle with straight, slightly flared collarette with subcylindrical neck, approximately one third the total length, which narrows slightly below the collarette. Chamber flanks are slightly curved to convex and widen just beyond the aperture diameter. Basal margin rounded to largely inconspicuous and base convex to flat with a prominent blunt mucron (up to 15 μm) located in the centre. Smooth vesicle wall.

Dimensions.

Overall length:	581 (633) 656 μm
Overall width:	153 (174) 236 μm
Oral tube length:	–
Neck width:	–
Aperture width:	103 (108) 113 μm
# specimens measured:	15

Remarks. *Conochitina* sp. E resembles Eisenack's (1937) holotype of *Conochitina proboscifera*, but it is smaller than those from the Silurian of the Baltic region. *Conochitina proboscifera* is typically a Lower Silurian species which has only been recovered from Llandovery to Wenlock sections. Further, Paris (2000, pers. comm.) indicated that the thickness of the wall of *Conochitina* sp. E is not consistent with material Laufeld (1974)

described and illustrated from the early Wenlock (*Monograptus riccartonensis* Zone) of Baltoscandia. Consequently, the taxonomy shall remain open, as any proposed affinity between the two species would be questionable at best. *Conochitina* sp. E also bears a resemblance to *Eremochitina baculata*. However, the flanks of *Conochitina* sp. E are more convex, and it shows a distinct tapering of the neck and a slightly flared collarette, features which are uncharacteristic for *E. baculata*.

Occurrence. Arenig: Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 34), *I. v. maximus* Zone.

Genus *Rhabdochitina* Eisenack 1931, emend. Paris 1981

Type species: *Rhabdochitina magna* Eisenack 1931

Remarks. Eisenack's (1931) original diagnosis of the genus *Rhabdochitina* included any relatively large, tube shaped chitinozoa. Taugourdeau (1966) further refined this definition by excluding claviform (conical) shaped individuals and restricting the genus to large (tall) cylindrically shaped forms without a distinct collarette and lacking appendages or ornament on the aboral pole. Later, Jansonius (1970) included the presence of a basal mucron as a diagnostic feature. However, if the validity of other mucron bearing genera is to be accepted (eg. *Siphonochitina, Eremochitina*), then this feature must be omitted from the strict definition of the taxon. Consequently, the genus *Rhabdochitina* will herein follow Taugourdeau's (1966) and Paris' (1981) definition and include "elongate, cylindrically

shaped forms, collarette undifferentiated, aperture straight, test smooth, basal margin rounded, base flat or convex, and remnants of a mucron only possibly present" (see Text-fig. 4.1).

Rhabdochitina magna (Eisenack 1931)

Plate 2, fig. 9; Plate 7, fig. 13.

Rhabdochitina magna Eisenack, 1931, p. 90, text-fig. 4, pl. 3, figs. 16, 18; ?Eisenack, 1939, p. 145, pl. B, fig. 9; Collinson & Schwalb, 1955, p. 18, text-fig. 5 I; Taugourdeau & DeJekhowsky, 1960, p. 1230, pl. 9, fig. 132, pl. 10, fig. 133; Benoit & Taugourdeau, 1961, p. 1411, pl. 5, figs. 53, 54; Eisenack, 1962a, p. 292, text-fig. 1, pl. 14, fig. 1, pl. 15, fig. 5; Bouché, 1965, p. 162, pl. 3, figs. 3, 4; Eisenack, 1965, p. 27, pl. 10, fig. 10; Jenkins, 1967, p. 466, pl. 74, figs. 6, 9, 10, 12; ?Rauscher & Doubinger, 1967b, p. 314, pl. 5, fig. 8; Eisenack, 1968, p. 167, pl. 32, fig. 1; Umnova, 1969, p. 328, pl. 1, figs. 1, 2; ?Rauscher & Doubinger, 1967a, p. 482, pl. 4, fig. 6; ?Atkinson & Moy, 1971, p. 241, pl. 1, fig. C; Chlebowski & Szaniawski, 1974, p. 225, pl. 3, figs. 1-3; Eisenack, 1976b, p. 187, pl. 2, figs. 8, 9; Achab, 1977a, p. 424, pl. 5, figs. 3, 4, 6, 10-12; Achab, 1978a, p. 310, pl. 3, figs. 8-10; Paris, 1979, p. 41, pl. 2, fig. 10; Grahn, 1980, p. 36, fig. 20 C, E; Grahn, 1981, p. 45, fig. 16 A, B; Paris, 1981, p. 197, pl. 13, fig. 19; Schallreuter, 1981, p. 130, pl. 18, figs. 3, 4; Grahn, 1982, p. 47, fig. 16 J-L; Melchin, 1982, p. 275, pl. 13, fig. 12; Achab,

1986b, p. 289, pl. 6, fig. 9; McClure, 1988, p. 2, fig. 12.

?*Rhabdochitina gallica* Umnova, 1969, pl. 1, figs. 3, 4.

Rhabdochitina cf. *magna* Neville, 1974, p. 201, pl. 6, figs. 7-17; ?Gao, 1968, pl. 2, figs. 1, 2; Achab, 1986b, p. 289; pl. 6, figs. 10, 11.

Description. Large tubular shaped vesicle with indistinguishable neck and body, and only very slightly wider at the base. Collarette straight and indistinct. Flanks straight but widen very slightly towards the base. Basal margin rounded and the base slightly convex to flat and may possess a basal scar or pore in the centre. In rare cases longitudinal deformation can make the basal margin appear more rounded. Wall smooth.

Dimensions.

Overall length:	838 (1127) 1506 μm
Overall width:	113 (191) 237 μm
Oral tube length:	--
Neck width:	--
Aperture width:	94 (122) 138 μm
# specimens measured:	15

Remarks. *Rhabdochitina magna* (Eisenack, 1931) is a very large, simple tubular shaped chitinozoan and rarely confused with other individuals. While *R. magna* superficially resembles *R. gracilis*, *R. gracilis* has a more slender form, its basal edge is broadly rounded and its base convex with a distinct basal process. The basal edge of *R. magna* is rounded and typically its base is flat and lacks a mucron. Illustrated specimens of *R. magna* by Taugourdeau & DeJekhowsky (1960) and Benoit & Taugourdeau (1961) suggest they

interpreted the species more widely and chose to include more variability than Eisenack's holotype.

Occurrence. Arenig: Western Brook North (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 52-A), *U. austrodentatus* Zone.

Stratigraphic Distribution. Eisenack (1962a) recorded common examples of *R. magna*, including the holotype (Eisenack, 1931), from the Ostseekalk and B_3 and C_1 of Estonia. Atypical forms were recovered from the Vagintenkalk of Reval, $B_{3\gamma}$, and the Echinosphaeritenkalk of Reval, C_1, the Chasmops-Kalk (Caradoc) of Böda, Öland, the Ordovician Rhenish Schiefergebirge, and Middle Ordovician, D_γ, of Bohemia. Later he recorded the species from the Kundan (B_3-upper Arenig to lower Llanvirn) to Aserian (C_{1a}-upper Llanvirn) and Nabalan (F_1-uppermost Caradoc) to Porkunian (F_2-upper Ashgill) of Estonia (Eisenack, 1962a, 1962c, 1965, 1968), and the *Vaginatum* Limestone (B_3-upper Arenig to lower Llanvirn) of Öland, Sweden (Eisenack, 1976a). In Gotland, Grahn (1982) described the species from the Upper Kukrusean to Idaverean (lowermost Caradoc-Middle Caradoc) and Rakverean to Pirguan/Jonstorp (Upper Middle Caradoc-Middle Ashgill), and from the Upper Langevojan (Upper Arenig) to Lower Valastean (Lower Llanvirn), Upper Aluojan (Lower Llanvirn), and Källa (Llandeilo) to Lower Dalby Limestones of Öland, Sweden (Grahn, 1980, 1981a).

In North America, the species has been reported from the subsurface lower Vaureal Formation (Lower Middle Ashgill) of Anticosti Island, Canada (Achab, 1977a, 1978), with

rare specimens recovered from the upper Bobcaygeon and Lindsay [Kirkfieldian to lowest Maysvillian (Caradoc)] of the Simcoe Group, southern Ontario, Canada (Melchin, 1982). Forms resembling *R. magna* (*R.* cf. *magna*) were also described from the Table Head Group (Caradoc) on the Port au Port Peninsula, western Newfoundland, Canada (Neville, 1974).

Other reports of the species distribution are from the Lower Ordovician (Arenig) to Lower Silurian (Llandovery) of the Djado Basin, Nigeria (Bouché, 1965), the Hope Shales (Llanvirn) to Lower Meadowtown Beds (lower Llandeilo) of the Welsh Borderland, Shropshire (Jenkins, 1967), the Russian Platform, Kunda stage (Llanvirn) (Umnova, 1969), the Holy Cross Mountains (Arenig?) at Miedzygórz, Warsaw (Chlebowski & Szaniawski, 1974), the base of Porto do Santa Anna Formation (Lower Caradoc), Buçaco syncline, Portugal (Paris, 1979), and the Tabuk Formation, Hanadir Shales (Llanvirn), northwest Arabia (McClure, 1988).

In the Sahara, Taugourdeau & Dejekhowsky (1960) gave the stratigraphical range for *R. magna* as Ordovician (Zone 2) to Silurian (Zone 3). Benoit & Taugourdeau (1961) listed it in nine horizons in the Ordovician (Arenig?) of North Africa (Sahara), while Paris (1981) recovered specimens from the upper part of the Pissot Formation (lower Llandeilo), south west of Domfront. In Portugal, *R. magna* is very rare in the Louredo Formation (Caradoc) and the Porto do Santa Anna (Ashgill).

Rhabdochitina tubularis (Umnova 1976)

Plate 4, figs. 23-25.

Rhabdochitina tubularis Umnova, 1976, p. 404, pl. 1, fig. 2; Achab, 1986a, p. 694, pl. 2, figs. 11-13.

Rhabdochitina cf. *tubularis* Achab, 1980, p.234, pl. 4, fig. 4.

Description. Narrow tubular or cylindrical vesicle, only several microns narrower at the aperture than the base. Neck and chamber indistinct, collarette straight and indistinct. Flanks straight, basal margin rounded and base convex to slightly hemispherical. Wall smooth.

Dimensions.

Overall length:	542 (582) 616 μm
Overall width:	99 (101) 103 μm
Oral tube length:	–
Neck width:	–
Aperture width:	79 (83) 85 μm
# specimens measured:	8

Remarks. *Rhabdochitina tubularis* (Umnova, 1976) is a simple, relatively undifferentiated chitinozoan species which is readily identified by its moderate size and its nearly perfect cylindrical shape. Though *R. tubularis* resembles *R. gracilis* (Eisenack, 1962a), *R. gracilis* is up to three times longer, half the width and it typically possesses a distinct basal process or indentation. Western Newfoundland specimens within this study are almost identical in size and shape to Achab's (1980, 1986a) material and are closely comparable to Umnova's

original description and illustration of the species.

Occurence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone.

Stratigraphic Distribution. The holotype was recovered from the Moscow syneclise within the Volkhov, Kunda and Tallinn horizons (Arenig-Llandeilo) of the Russian Platform (Umnova, 1976). Achab later reported it from the Levis Formation, Zone B (Lower Arenig) of Quebec (1980) and the Cow Head Group (Arenig) of western Newfoundland, Canada (Achab, 1986a).

Rhabdochitina usitata (Jenkins 1967)

Plate 4, figs. 27-31; Plate 8, fig. 20.

Rhabdochitina usitata Jenkins, 1967, p. 468, pl. 75, fig. 1; Jenkins, 1969, p. 29, pl. 9, figs. 10-12; Neville, 1974, p. 202, pl. 7, figs. 12, 13, 16-18; Martin, 1978, p. 80, pl. 12.1, figs. 1, 2, 4, 9, 15, 18; Melchin, 1982, p. 278, pl. 13, figs. 9, 10; Achab, 1984, p. 138, pl. 4, figs. 1, 2, 5; McClure, 1988, pl. 4, fig. 4.

Description. Blunt tubular or weakly conical vesicle with indistinguishable neck and chamber. Aperture straight, collarette indistinct, 80-90 % maximum width. Flanks straight. Basal margin inconspicuous and base hemispherical to rounded. Rare specimens posses a small, blunt basal mucron. Wall very smooth.

Dimensions.

Overall length:	493 (596) 683 μm
Overall width:	113 (130) 148 μm
Oral tube length:	–
Neck width:	–
Aperture width:	91 (94) 101 μm
# specimens measured:	18

Remarks. *Rhabdochitina usitata* was not reported so far from the Lower Ordovician (Arenig). Jenkins (1967) based the species on material from Llanvirnian to Caradocian strata of Shropshire. It is easily distinguished from other common rhabdochitinids, especially *R. magna*, in having a hemispherical base; *R. magna* has a flat base, and *R. usitata* is only about half the total length of known specimens of *R. magna*. Jenkins also suggests that *R. usitata* will rarely have a stout basal process attached to its centre. Though this feature seems to fall outside the strict definition of the species, it is presently accepted as a valid morphological variation.

Occurrence. Arenig: Cow Head North (CHN 11.4-B), *P. fruticosus* Zone; Cow Head South (CHS 13.6-A), *I. v. maximus* Zone; Western Brook South (WBS 34), *I. v. maximus* Zone.

Stratigraphic Distribution. Jenkins (1967) first recovered several hundred single tests of *Rhabdochitina usitata* from the Hope Shales to the *Onnia* Beds (Llanvirn-Caradoc) of the Welsh Borderland, Shropshire. In North America the species has been recovered from the base of the Llanvirn to upper Caradoc in North-Central Florida, U.S.A. (Andress *et al.*,

1969), the Upper Viola Limestone (upper caradoc-lower Ashgill) of Oklahoma, U.S.A. (Jenkins, 1969), the Cow Head Group (Arenig) and the Middle Table Head Formation (Llanvirn and Caradoc) of western Newfoundland, Canada (Neville, 1974; Martin, 1978), and the Trenton Formation (middle Caradoc) of Anticosti Island, Canada (Achab, 1984). Both rare and common examples have been found in the upper Bobcaygeon and lowest Verulam in the Campbellford area, and in the lower middle parts of Lindsay [Kirkfieldian to Edenian (Caradoc)], within the Simcoe Group of southern Ontario, Canada (Melchin 1982). More recently, McClure (1988) described individuals from the Tabuk Formation (Caradoc-Ashgill) of the Ra'an Shale, northwest Arabia.

Rhabdochitina sp.

Plate 2, fig. 10.

Description. Very elongate, tubular to cylindrical vesicle, slightly wider at the base, with straight, cylindrical "oral tube" and indistinct collarette. Basal margin is sharp but appears to have been fractured. Base flat to only slightly convex. Wall smooth.

Dimensions.

Overall length:	1188 μm
Overall width:	94 μm
Oral tube length:	--
Neck width:	--
Aperture width:	74 μm
# specimens measured:	1

Remarks. *Rhabdochitina* sp. closely resembles *Rhabdochitina canna* (Deflandre, 1942) illustrated by Benoit & Taugourdeau (1961), which is similarly very narrow and elongate, cylindrical in shape, and has a sharp basal margin. However, *Rhabdochitina* sp. also resembles an individual which Taugourdeau (1965) identified as a melanosclerite from the Lower Ordovician Bromide formation of Oklahoma, U.S.A. Whether *Rhabdochitina canna* is currently a valid chitinozoan taxon or Taugourdeau's identification was accurate, is uncertain. Its overall conformance with the shape of other rhabdochitinids seems to justify its generic assignment.

Occurrence. Arenig: St. Paul's Inlet (SPI 78), *I. v. maximus* Zone.

Subfamily TANUCHITININAE Paris 1981

Genus *Laufeldochitina* Paris 1981

Type species: *Cyathochitina stentor* Eisenack 1937

Remarks. After restricting the genus *Cyathochitina*, Paris (1981) proposed the genus *Laufeldochitina* to include forms (now excluded from that genus) with the following definition, "Elongate chitinozoa; chamber claviform to ovoid; oral tube generally flared towards the aperture; neck and chamber merge imperceptibly; basal margin rounded and base rounded to slightly convex; test made up of two membranes; surface smooth, finely granulated or sometimes striated; carina below the base, generally truncated or flared aborally, and separated from the chamber by a well defined constriction; mucron reduced or

absent; tubular prosome situated at the base of the neck; chains absent."

The distinction between *Laufeldochitina* and *Cyathochitina* is based primarily on the position and development of the carina (see Text-fig. 4.1). Unlike the cyathochitinids, the carina of *Laufeldochitina* projects aborally and is located almost exclusively within the lateral margins such that the maximum diameter of the chamber does not usually coincide with the diameter of the basal margin. Further, *Laufeldochitina* is typically longer and possesses a narrow waist or depression at the juncture between the carina and the base, which is not well developed within the genus *Cyathochitina*.

Laufeldochitina sp.

Plate 3, figs. 22, 23.

Description. Elongated campanulate shaped vesicle, somewhat resembling a trumpet. Orally, the vesicle is cylindrical to weakly conical and tapers slightly towards the aperture. Collarette straight and indistinct; rarely flared. Aborally, the vesicle bulges out slightly above the basal margin at approximately 70 to 80% the length, then narrows forming a waist-like depression below which the carina extends aborally and laterally. Maximum diameter at the basal margin, inclusive of the carina. Basal margin sharp and base flat to concave. Vesicle wall may possess longitudinal striations but otherwise lacks ornament.

Dimensions.

Overall length:	695 (849) 912 μm

Overall width:	158 (191) 222 μm
Oral tube length:	--
Neck width:	--
Aperture width:	74 (85) 99 μm
# specimens measured:	5

Remarks. *Laufeldochitina* sp. resembles Eisenack's (1937) holotype of *Conochitina stentor*, but Eisenack's forms possess longitudinal striations which were not found in the Newfoundland material. Furthermore, *L. stentor* (Eisenack, 1937) has only been recovered from uppermost Ordovician and Lower Silurian sections of the Baltic and north Africa. Although Paris (1981) showed that the carina of *L. stentor* extends slightly beyond the lateral margin and is often the widest portion of the vesicle, much like that of the Newfoundland material, this feature by itself is insufficient to make a specific identification.

Occurrence. Arenig: Western Brook South (WBS 52-A), *U. austrodentatus* Zone.

Genus *Tanuchitina* Jansonius 1964, emend. Paris 1981

emend. Paris, Grahn, Nestor & Lakova 1999

Type species: *Tanuchitina ontariensis* Jansonius 1964

Remarks. In his original diagnosis of the genus, Jansonius (1964) included elongate forms which were conical to cylindrical in shape, with no distinction between neck and chamber, and a cylindrical flange or carina situated on the base inside the basal margin. Paris (1981) pointed out that this definition conformed almost exclusively to the type species (*T.*

ontariensis) and felt that it was too restrictive to account for the diversity of forms that were reasonably included within the genus. Hence, he slightly modified Jansonius' original diagnosis to include, "elongate chitinozoa, vesicle subcylindrical, fusiform or weakly conical; flexure indistinct or slightly noticeable; chamber sometimes bulging (swollen); maximum diameter occurs below a short carinal membrane which is positioned within the basal margin (which is rounded and very reduced); test surface smooth, rarely rugose; tubular prosome or mucron absent or only slightly developed" (see Text-fig. 4.1). Within this emended diagnosis, Paris noted two important taxonomic elements: the maximum diameter of the chamber is always situated below the basal margin; and the angle of the basal margin is less than or equal to 90 degrees with the chamber.

Recently, Paris *et al.* (1999) further emended the definition of the genus *Tanuchitina* and subsequently transferred the conical forms possessing a carina on the basal margin into a new genus, *Hyalochitina* Paris & Grahn (see Paris *et al.*, 1999).

Tanuchitina sp.

Plate 4, figs. 16-22; Plate 7, fig. 19.

Description. Tubular or cylindroconical vesicle with indistinct oral tube and chamber. Collarette generally straight and indistinct but vesicle may be very weakly flared at the aperture. Flanks straight, slightly wider towards the base, with maximum diameter at the basal margin. Basal margin sharp and possesses a thin, membranous carina which projects

aborally and only slightly laterally. Base flat to convex but generally does not extend below the carina. Wall smooth with no ornament.

Dimensions.

Overall length:	675 (863) 1003 μm
Overall width:	119 (149) 178 μm
Oral tube length:	–
Neck width:	–
Aperture width:	91 (112) 119 μm
# specimens measured:	15

Remarks. *Tanuchitina* sp. bears a distinct resemblance to *Cyathochitina protocalix* (Paris, 1981) and *Cyathochitina hyalophrys* (now *Hyalochitina*) Eisenack 1959. However, Paris (2000, pers. comm.) pointed out that the details of the aboral region of the Newfoundland specimens are inconsistent with the holotype, and that *C. hyalophrys* is typically a Silurian (Wenlockian) species that has not been documented from the Lower Ordovician.

Earlier, Miller (1976) pointed out the resemblance between members of the genus *Tanuchitina* (eg. *Tanuchitina ontariensis* Jansonius 1964 and *T. bergstroemi* Laufeld 1967) and *C. hyalophrys* Eisenack 1959, and suggested that *Tanuchitina* was a phylogenetic branch from the cyathochitinids, with *C. hyalophrys* representing a transitional form between the two genera. Unfortunately, this could not be proven conclusively from my study and was only inferred from the shared morphological features of the forms in question by Miller (1976). However, it does suggest that *C. protocalix* and *C. hyalophrys* may have a close relationship, and that they both may share affinity with several Newfoundland specimens

of *Tanuchitina* sp.

Occurrence. Arenig: Cow Head North (CHN 11.4-B), *P. fruticosus* Zone; Cow Head South (CHS 11.30), *I. v. lunatus* Zone; (CHS 13.6-A), *I. v. maximus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 52-A), *U. austrodentatus* Zone; (WBS 62), *U. austrodentatus* Zone.

Subfamily EREMOCHITININAE Paris 1981

Genus *Eremochitina* Taugourdeau & DeJekhowsky 1960

Type species: *Eremochitina baculata* Taugourdeau & DeJekhowsky 1960

Remarks. In the original diagnosis by Taugourdeau & DeJekhowsky (1960), the genus *Eremochitina* includes "tall, elongated chitinozoans, claviform in shape, with a rounded to ovoid chamber, and the presence of a distinct basal tube or copula (see Text-fig. 4.1) projecting aborally." Paris (1981) further added that the copula opens distally and represents an extension of the external membrane or periderm, which Taugourdeau & DeJekhowsky propose as having a role in the organization of colonies. Laufeld (1967) had proposed an emendation allowing the transfer of *Lagenochitina dalbyensis* to the genus *Eremochitina*. Paris (1981) did not think this was justified as the species *dalbyensis* lacks a distinct copula or mucron, which is a characteristic of the genus. Rather, the resemblance of this species to other lagenochitinids suggests that it more appropriately belongs to *Lagenochitina*. Andress

et al. (1968) attempted to enlarge the genus *Eremochitina* by including forms usually attributed to *Velatachitina* (Poumot, 1968) or *Siphonochitina* (Jenkins, 1967) which they considered synonymies of the genus. However, Paris (1981) didn't share their views and maintained the three genera as separate and distinct (see Paris, 1981; Miller, 1996 for illustrations).

Eremochitina sp. cf. ***E. baculata*** (Taugourdeau & DeJekhowsky 1960)

Plate 3, fig. 20.

Description. Vesicle is overall tubular in shape while its silhouette resembles a "condom". Orally, the "neck" is cylindrical, above which sits a distinctly flared collarette. At approximately half the vesicle length, the wall narrows at a small depression then flares towards the base. Basal edge blunt and forms the widest part of the entire vesicle; base convex to slightly rounded, and possess a large blunt mucron in the centre. Vesicle wall is smooth.

Dimensions.

Overall length:	808 µm
Overall width:	143 µm
Oral tube length:	--
Neck width:	--
Aperture width:	143 µm
# specimens measured:	1

Remarks. The lone specimen questionably designated as *Eremochitina* sp. cf. *E. baculata*

closely resembles an elongated form of *Linochitina cingulata* illustrated by Eisenack (1968) from Silurian rocks of the Baltic. The morphological features exhibited by this individual from western Newfoundland: elongated conical form, rounded base, large basal mucron and lack of a distinct flange or carina on the periphery of the basal margin, suggest that it more appropriately belongs to the genus *Eremochitina* and likely represents the species *baculata*. Unfortunately, its compressed and distorted shape precludes a definite specific assignment.

Occurrence. Arenig: Western Brook South (WBS 52-A), *U. austrodentatus* Zone.

Family LAGENOCHITINIDAE Eisenack 1931, emend. Paris 1981

Subfamily LAGENOCHITININAE Paris 1981

Genus *Amphorachitina* Poumot 1968

Type species: *Amphorachitina conifundas* Poumot 1968

Remarks. The genus *Amphorachitina* was erected by Poumot (1968) and includes those chitinozoans which have a fusiform silhouette (see Text-fig. 4.1). Typically, the neck is either conical and weakly tapering towards the aperture, or flared at the collarette, while the chamber is elongated and ovoid with an ogival base which often possesses a distinct mucron. The genus is distinct from *Lagenochitina* based on the shape of the chamber and base which is much more fusiform and ogival in *Amphorachitina*. The absence of a large, distinct copula (mucron) distinguishes it from *Eremochitina*.

Amphorachitina conifundas (Poumot 1968)

Plate 6, figs. 17, 18.

Amphorachitina conifundas Poumot, 1968, p. 48, pl. 1, figs. 4-6.

Description. Vesicle is fusiform in shape with subcylindrical neck that tapers slightly towards the aperture. Collarette straight and indistinct. Flexure weakly defined, shoulders absent. Chamber elongate and fusiform in shape with maximum diameter at the chamber midpoint approximately 25 to 30% the length from the base. Basal margin inconspicuous and base ogival with a blunt mucron in its centre. Vesicle wall smooth.

Dimensions.

Overall length:	483 (519) 555 μm
Overall width:	148 (166) 185 μm
Oral tube length:	187 (205) 224 μm
Neck width:	98 (100) 102 μm
Aperture width:	94 (96) 99 μm
# specimens measured:	2

Remarks. The pair of specimens of *A. conifundas* are quite comparable in size and form to Poumot's (1968) paratype of the species from the Tremadoc of Algeria. Its fusiform shape, distinctly ogival base and lack of a large basal mucron separates this species from similar eremochitinids (e.g. *E. mucronata*) and lagenochitinids.

Occurence. Tremadoc: Martin Point South (MPS 42-C), *A. victoriae* Zone; **Arenig:** Cow Head North (CHN 9.6-B/C), *T. approximatus* Zone.

Stratigraphic Distribution. Subsurface Tremadoc, Ed Gassi region of Algeria (Poumot, 1968).

Amphorachitina sp.

Plate 6, figs. 19-21.

Description. Jug shaped (lagenoid) vesicle with a long narrow cylindrical oral tube distinct from the chamber approximately half the total length. Collarette straight and indistinct, but may flare only slightly; aperture entire. Flexure distinct but shoulders are short and narrow. Chamber swollen to weakly fusiform in shape with maximum diameter at or just below the shoulders. Basal margin inconspicuous and base bluntly ogival. Vesicle wall smooth.

Dimensions.

Overall length:	660 (713) 759 μm
Overall width:	197 (201) 204 μm
Oral tube length:	238 (262) 291 μm
Neck width:	91 (104) 121 μm
Aperture width:	98 (102) 110 μm
# specimens measured:	3

Remarks. The basic shape of *Amphorachitina* sp. ressembles Laufeld's (1967) *L. dalbyensis* from the Caradoc of Dalarna, Sweden. However, *Amphorachitina* sp. is slightly larger, has a slightly sharper distinction between neck and chamber and more of a blunt base. Further, *L. dalbyensis* has not been documented from the Lower Ordovician. Earlier, Martin (1978)

identified an unspecified *Amphorachitina* sp. from the Arenig of the Cow Head Group (Ledge Section CHN, bed 9) western Newfoundland, which bears a close resemblance to examples of *Amphorachitina* sp. within this study (pl. 6, fig. 18). Although her specimen has a slightly more ogival (sharply ovoid) base, these two taxa appear to be conspecific.

Occurrence. Tremadoc: St. Paul's Inlet (SPI 43-I), *A. victoriae* Zone; Martin Point South (MPS 42-C), *A. victoriae* Zone.

Genus *Lagenochitina* Eisenack 1931

emend. Paris, Grahn, Nestor & Lakova 1999

Type species: *Lagenochitina baltica* Eisenack 1931

Remarks. With the exception of Paris (1981), who erected the Subfamily Lagenochitininae, and some specific modifications by others, the diagnosis of the genus *Lagenochitina* has undergone little change since it was first erected by Eisenack in 1931. The genus *Lagenochitina* is relatively simplistic and rarely confused with other genera: "chamber spherical to ovoid; neck well defined, separated from the chamber by a flexure and well defined shoulders; test wall smooth or finely granulated, and lacking spines, cones or tubercles; copula absent but mucron sometimes present; prosome at the base of the neck" (Paris, 1981). Recently, however, Paris *et al.* (1999) have emended this definition and transferred forms with glabrous (i.e. totally smooth) spherical chambers to the genus *Sphaerochitina* (Eisenack, 1955a), thereby creating much less ambiguity within the genus

Lagenochitina (Eisenack, 1931) (see Text-fig. 4.1). Grahn (1980) and others have also informally, and quite accurately, described the genus *Lagenochitina* as bottle-, jug- or flask-shaped which has subsequently led to the increasing use of the descriptive term "lagenoid".

Lagenochitina sp. cf. ***L. baltica*** (Eisenack 1931)

Plate 5, figs. 1-4.

Description. Bottle or flask shaped vesicle with short, slightly tapering oral tube approximately 25 to 30 % the total length. Collarette straight and indistinct. Flexure and shoulders present but broadly rounded and often only moderately defined. Chamber distinct and ovoid to rounded in shape. Flanks convex with maximum diameter at approximately the chamber mid point. Basal margin rounded and base rounded to convex. Wall smooth.

Dimensions.

Overall length:	503 (613) 695 µm
Overall width:	251 (294) 340 µm
Oral tube length:	98 (153) 197 µm
Neck width:	123 (151) 168 µm
Aperture width:	103 (105) 109 µm
# specimens measured:	5

Remarks. Individuals identified as *Lagenochitina* sp. cf. *L. baltica* resemble Eisenack's (1931) original species, but the size range recorded is about twice that of the holotype and those subsequently reported by Jenkins (1967), Laufeld (1967), Achab (1977a) and Berström & Grahn (1984); however, the length to width ratio of approximately 2:1 is consistent with

most accounts. Neville (1974) recorded large specimens of *L. baltica* from the Caradoc of the Table Head Formation, western Newfoundland, which were only slightly smaller than those of the Cow Head Group but showed considerably more variation in overall shape, from long slender forms to short stout forms. Neville also noticed that the development of the shoulders in his populations varied significantly, resulting in individuals with poorly defined flexures, and tapering rather than cylindrical necks, very similar to my western Newfoundland specimens. Consequently, he felt a separation of his specimens of *L. baltica* and *L.* cf. *baltica* was warranted. Inasmuch as both forms seem to grade into each other, Neville (1974) decided this separation of forms was necessary, but arbitrary and somewhat subjective; it may not be the result of true biological species variation. Except for Nautiyal (1966), who recovered similar forms as *L. baltica* from the lower-middle Arenig Scotia Formation of Bell Island, Conception Bay, Newfoundland, no well-documented examples of *L. baltica* within the Lower Ordovician (Arenig) have been found, which could suggest misidentification of those individuals by Nautiyal. Nevertheless, western Newfoundland forms of *Lagenochitina* sp. cf. *L. baltica* seem to share affinity with those from Bell Island, which not only show a more cosmopolitan distribution, but may help in establishing a connection between Laurentian and Gondwanan domains not previously documented within eastern Canada. Traditionally, *L. baltica sensu stricto* has been used as a formal Caradocian index fossil; this calls to question the certainty of the present taxonomic assignment. However, the close resemblance of the larger Newfoundland specimens with Eisenack's (1931) holotype and a plethora of illustrations and descriptions of the species from other

publisbed accounts, cannot discount the possibility that these individuals are related, and possibly even represent the same taxon.

Occurrence. Arenig: Cow Head North (CHN 9.17 Akz), *T. akzharensis* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone.

Lagenochitina boja (Bockelie 1980)

Plate 5, fig. 7.

Lagenochitina boja Bockelie, 1980, p. 4, pl. 1, figs. 8, 17-19, 21, 22, p. 8, fig. 7a.

?*Linochitina* sp. Nolvak & Grahn, 1993, p. 265, pl. 6, fig. C.

Description. Large jug shaped vesicle with an elongate cylindrical neck and distinctly flared collarette. Flexure present but very weakly defined. Shoulders absent as neck and chamber merge almost imperceptibly. "Chamber" conical in shape. Below the neck (at about half the vesicle's length) the chamber flanks widen towards the base with maximum diameter occurring at the basal margin. Basal margin broad and well rounded, base flat to slightly convex. Vesicle wall without ornament but appears to posses a granulated or rugose texture.

Dimensions.

Overall length:	894 (949) 976 µm
Overall width:	251 (268) 296 µm
Oral tube length:	--
Neck width:	168 (176) 182 µm
Aperture width:	207 (221) 239 µm

specimens measured: 4

Remarks. *Lagenochitina boja* resembles *L. esthonica* (Eisenack, 1955b) and *L. maxima* (Taugourdeau & DeJekhowsky, 1960) in several respects. The most important differences between the three are the shape of the chamber and the test surface. The chamber of *L. esthonica* is more broadly spherical to ovoid than that of *L. boja* and lacks the rugose surface texture that Bockelie (1980) suggests is often observed in *L. boja*. The chamber of *L. maxima* is more elongate and almost cylindrical, often with a small depression at its midpoint, and its test wall smooth. Bockelie (1980) further suggested that a significant difference exists between the maximum diameter and neck diameter of *L. esthonica* and *L. boja*. However, the large amount of variability that has been reported within populations of *L. esthonica* precludes this feature as being an accurate means of comparison. Although the ratio of maximum length to maximum diameter of *L. boja* shows a significant difference with *L. esthonica*, *L. maxima* is similar (between 4 and 4.5). Statistically, the distinction between *L. maxima* and *L. boja* is much less pronounced than that seen in morphological comparison of the two species. While not presently regarded as conspecific, they may represent points on an evolutionary continuum. Unfortunately, this opinion is only based on present observations and material illustrated and described by Bockelie (1980), rather than on extensive statistical measurements from either population.

Occurrence. Arenig: Cow Head North (CHN 9.17 Akz), *T. akzharensis* Zone.

Stratigraphic Distribution. Valhallfonna Formation (late Arenig-early Llanvirn), Ny Friesland, Spitsbergen (Bockelie, 1980).

Lagenochitina capax (Jenkins 1967)

Plate 5, fig. 5; Plate 8, fig. 5.

Lagenochitina capax Jenkins, 1967, p. 465, pl. 73, fig. 3 (non fig. 2).

Description. Stout vesicle of general lagenoid shape, with a short and wide oral tube approximately 60 to 70% of the maximum width. Neck cylindrical, wider than long. Collarette straight and indistinct. Flexure present, shoulders rounded and weakly defined. Rounded flanks give the chamber a swollen appearance with maximum diameter between the shoulders and the chamber midpoint. Basal margin rounded and the base convex to flat. Vesicle wall slightly pitted but lacks ornament.

Dimensions.

Overall length:	456 (471) 478 μm
Overall width:	277 (279) 283 μm
Oral tube length:	133 (138) 144 μm
Neck width:	156 (163) 167 μm
Aperture width:	172 (175) 178 μm
# specimens measured:	4

Remarks. In the original description of the species, Jenkins (1967) illustrated two specimens of *Lagenochitina capax* (pl. 73, figs. 2, 3). Paris (1981) proposed that the

resemblance of one of Jenkins' illustrations (fig. 2, *L. capax*) to *L. deunffi* (Paris, 1974) made the two conspecific. The stout form of *L. capax*, its short cylindrical neck, weak shoulders and swollen chamber, easily distinguish it from other lagenochitinids; thus, it should be maintained as a distinct taxon; Paris (1981) left the holotype of *L. capax* (Jenkins, 1967, pl. 73, fig. 3) intact. Specimens of *L. capax* from western Newfoundland are approximately 40% larger than the holotype from the Caradoc of Shropshire, but are consistent with the form and ratio of length to width of approximately 1.6:1.

Occurrence. Arenig: Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Stratigraphic Distribution. Glenburrell Beds (base of Caradoc) of the Welsh Borderland, Shropshire (Jenkins, 1967); base of the Porto do Santa Anna Formation (lower Caradoc), Buçaco syncline, Portugal (Paris, 1979).

Lagenochitina combazi (Combaz & Péniguel 1972)

Plate 5, fig. 6.

Lagenochitina tumida Combaz & Péniguel, 1972, p. 146, pl. 4, fig. 8.

Lagenochitina combazi Finger, 1982, p. 1488; Playford & Miller, 1988, p. 24, pl. 3, figs. 3-9, pl. 4, figs, 11, 12.

Lagenochitina cf. *L. combazi* Achab, 1986a, p. 691, pl. 2, figs. 7, 9 (?8), pl. 4, figs. 9, 10

Non: *Lagenochitina tumida* Umnova, 1969, p. 338, pl. 2, figs. 33, 34.

Description. Short jug or bottle shaped vesicle of typical lagenoid shape with distinct neck and chamber. Oral tube straight to subcylindrical while the "collarette" is slightly wider at the aperture without being distinctly flared. Flexures and shoulders both present and well defined, flexures more rounded than sharp. Maximum diameter of the vesicle occurs at the chamber just below the shoulders, which narrows slightly towards the base. Basal margin rounded and the base rounded to convex. Vesicle wall lacks ornament.

Dimensions.

Overall length:	355 (366) 384 µm
Overall width:	198 (209) 222 µm
Oral tube length:	104 (108) 113 µm
Neck width:	89 (93) 97 µm
Aperture width:	99 (105) 108 µm
# specimens measured:	3

Remarks. Finger (1982) renamed the species *L. tumida* (Combaz & Péniguel, 1972; pl. 4, fig. 8) as *L. combazi*, to avoid confusion of this later homonym with Umnova's (1969) previous usage of the epithet *tumida* for a different lagenochitinid species; he regarded *L. combazi* as a "primary junior homonym" to *L. tumida* of Umnova (1969; pl. 2, figs. 33, 34). *L. combazi* (Finger, 1982) resembles other stout lagenochitinids, particularly *L. deunffi* (Paris, 1974) and *L. prussica* (Eisenack, 1931). However, *L. combazi* is larger, its chamber flanks are straighter and its base convex to flat. Both *L. deunffi* and *L. prussica* have a shorter oral tube and a more subspherical chamber. *Lagenochitina combazi* also differs from the British Caradocian species *L. capax* (Jenkins, 1967) in having a shorter total length and a

neck that is not as wide as the chamber. Specimens of *Lagenochitina combazi* from this study are almost identical in form and size to those Achab (1986a) recovered from the Arenig of the Cow Head Group, western Newfoundland and the Levis Formation, Quebec, and are consistent with Combaz & Péniguel's (1972) holotype.

Occurrence. Arenig: Western Brook North (WBN 18-A), *T. akzharensis* Zone; (WBN 29), *D. bifidus* Zone.

Stratigraphic Distribution. Nambeet Formation, Canning Basin, Zone 0_2 (lower Arenig), Australia (Combaz & Péniguel, 1972); Levis Formation, Zone C (Arenig), Quebec (Achab 1986a); Cow Head Group (Arenig), western Newfoundland, Canada (Achab, 1986a). Coolibah and Nora Formations (middle-late Arenig), Georgina Basin, Queensland, Australia (Playford & Miller, 1988).

Lagenochitina cylindrica (Eisenack 1931)

Plate 5, figs. 8-11.

Lagenochitina cylindrica Eisenack, 1931, p. 81, pl. 2, figs. 18, 19; Taugourdeau & DeJekhowsky, 1960, p. 1228, fig. 2; Taugourdeau, 1961, p. 146; Bouché, 1965, p. 162, pl. 3, figs. 7, 8; Jenkins, 1967, p. 463, pl. 74, figs. 1-3; Eisenack, 1968, p. 157, pl. 31, figs. 14, 15; Combaz & Péniguel, p. 1972, 145, pl. 4, fig. 7; Melchin, 1982, p. 265, pl. 13, fig. 4.

Description. Small bottle shaped vesicle with cylindrical to slightly tapering oral tube and straight, indistinct collarette. Flexure and shoulders present but weak and poorly defined. Flanks straight to slightly curved making the chamber appear cylindrical such that the entire vesicle resembles a long neck beer bottle. Though there is little difference between the basal width and the "chamber" width, maximum diameter occurs at about the chamber midpoint. In some individuals a faint waist is developed which is slightly narrower than both the shoulders and the base; in others the chamber may be slightly convex or swollen. Basal margin rounded to inconspicuous and base flat to convex, though individuals with well rounded bases are not uncommon. Wall smooth.

Dimensions.

Overall length:	441 (562) 611 μm
Overall width:	158 (171) 197 μm
Oral tube length:	113 (187) 245 μm
Neck width:	91 (116) 123 μm
Aperture width:	89 (107) 121 μm
# specimens measured:	10

Remarks. *Lagenochitina cylindrica* (Eisenack, 1931) is not well documented from Lower Ordovician strata. Bouché (1965) recovered several specimens from the lower 80 metres (boring Kourneida 1) of the Djado Bassin, southwestern Libyia, which had been previously dated as Arenig using graptolites. Western Newfoundland specimens are slightly larger than Eisenack's (1931) or Jenkins' (1967) material but are consistent with the basic shape and length to width ratio of approximately 3:1. The chamber length between 60 and 70 % of the

total length, and neck diameter between 55 and 65 % of the maximum, are also consistent with Jenkins' material. One of Eisenack's original illustrations had a definite waist or narrowing of the vesicle below the shoulders at the chamber midpoint. Jenkins (1967) also recorded this feature in several British specimens and noted that although the waist is supposedly characteristic of this species, it is not well developed in all individuals. Typically, the flanks are quite cylindrical but in rare cases the chamber may appear slightly swollen or convex.

Occurrence. Arenig: Cow Head South (CHS 11.30), *I. v. lunatus* Zone; St. Paul's Inlet (SPI 78), *I. v. maximus* Zone. Western Brook South (WBS 52-A), *U. austrodentatus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. Grauer Limestone (Silurian) of the Baltic (Eisenack, 1931); Silurian of Aquitaine (Taugourdeau, 1961); Lower Ordovician (Arenig) to Upper Silurian (Wenlock), Djado Basin, Nigeria (Bouché, 1965); Hope Shales (Llanvirn), Welsh Borderland, Shropshire (Jenkins, 1967); Zone 4 (Silurian) of the Sahara, south of Algeria (Taugourdeau & DeJekhowsky, 1960); Middle Ordovician of the Sahara (Benoit & Taugourdeau, 1961); Nambeet Formation, Zone 0_2 (lower Arenig) of the Canning Basin, Australia (Combaz & Péniguel, 1972); lone specimen from the middle Bobcaygeon [lowest Kirkfieldian (Caradoc)], Simcoe Group, southern Ontario, Canada (Melchin, 1982).

Lagenochitina destombesi (Elaouad-Debbaj 1988)

Plate 5, figs. 12-15, 21.

?*Lagenochitina shelvensis* Jenkins, 1967, p. 464, pl. 74, figs. 7, 8.

?*Lagenochitina esthonica* Combaz & Péniguel, 1972, p. 145, pl. 4, figs. 1, 2.

Lagenochitina destombesi Elaouad-Debbaj, 1988, p. 91, pl. 7, figs. 1, 4-6, 10-12, 15, 17, 20.

Description. Large jug or flask shaped (lagenoid) vesicle with short cylindrical to weakly tapering neck, approximately one third the total length, and slightly flared collarette just at the aperture. Flexure and shoulders rounded and poorly defined, shoulders often absent. Flanks curved, chamber conical to ovoid (swollen) in shape. Maximum diameter in lower half of the chamber just below the mid point. Basal margin rounded and base convex to weakly hemispherical. Wall smooth.

Dimensions.

Overall length:	513 (569) 628 µm
Overall width:	192 (224) 246 µm
Oral tube length:	133 (138) 147 µm
Neck width:	113 (121) 137 µm
Aperture width:	123 (146) 153 µm
# specimens measured:	10

Remarks. Examples of *L. destombesi* within the present study are identical to those identified by Elouad-Debbaj (1988) from the Lower Fezouata Formation (Tremadoc) of the middle Anti-Atlas, Morocco. The overall ovoid shape of the vesicle chamber bears a

resemblance to forms of *L. esthonica*, but its weakly flared collarette, poorly defined flexure and shoulders, and gradual merging of the neck and chamber suggest that *L. destombesi* is distinct enough to be regarded as a separate taxon. While *L. destombesi* closely compares to Achab's (1980) *Conochitina ventriosa*, *L. destombesi* has a clear distinction between neck and chamber and its chamber is more swollen, consistent with the form of the genus *Lagenochitina* (Text-fig. 4.1). The close resemblance between *L. destombesi* and *L. shelvensis* (Jenkins, 1967) from the Caradoc of Shropshire suggest the possibility that the two are synonymous. Unfortunately, the scarcity of present specimens of *L. destombesi* does not permit a critical comparison.

Occurrence. **Tremadoc:** Martin Point South (MPS 42-C), *A. victoriae* Zone; **Arenig:** Cow Head South (CHS 11.30), *I. v. lunatus* Zone; St. Paul's Inlet (SPI 55), *T.akzharensis* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone.

Stratigraphic Distribution. The type material was recovered from the Lower Fezouata Formation (Tremadoc) of the Anti-Atlas, Morocco (Elaouad-Debbaj, 1988).

Lagenochitina esthonica (Eisenack 1955b)

Plate 5, figs. 16-20, 22-28; Plate 7, fig. 20; Plate 8, figs. 1, 2, 16-18, 21; Plate 9, fig. 1.

Lagenochitina esthonica Eisenack, 1955b, p. 311, pl. 1, figs. 8, 9; ?Jenkins, 1967, p. 463, pl. 74, figs. 4, 5; Eisenack, 1968, p. 156, pl. 24, fig. 10, pl. 29, fig. 25, text-fig. 1;

Gao, 1968, pl. 3, figs. 3-6, 10-15, pl. 4, figs. 1-3, 7; Evitt, 1969, p. 472, text-fig. 18-12; Jenkins, 1970b, pl. 4, fig. 17; ?Combaz & Peniguel, 1972, p. 146, pl. 4, figs. 1, 2; Obut, 1973, pl. 10, figs. 6-8; ?Eisenack, 1976a, p. 186, pl. 2, fig. 1, text-fig. 2; Eisenack, 1976b, fig. 6, 22-23; Bockelie, 1978, figs. C, D; Bockelie, 1980, p. 12, pl. 2, figs. 1-7, text-fig. 7C, 8; ?Grahn, 1980, p. 32, fig. 19, A-D; Achab, 1980, p. 234, pl. 3, figs. 1-6; ?Paris, 1981, p. 248, pl. 10, figs. 15, 20; Grahn, 1984, p. 22, pl. 4, figs. F, G; Paris & Mergl, 1984, p. 55, pl. 4, figs. 1-6; Achab, 1986a, p. 693, pl. 2, figs. 16-18, pl. 4, figs. 1-3; ?Elaouad-Debbaj, 1988, p. 92, pl. 7, fig. 2; Paris, 1996, pl. 1, fig. 12.

Lagenochitina cf. *esthonica* Chlebowski & Szaniawski, 1974, p. 224, pl. 2, fig. 4; ?Melchin, 1982, p. 267; pl. 13, fig. 3.

?*Lagenochitina* sp. Achab, 1982, p. 1298, pl. 2, figs. 1-3, 8.

Description. Bottle, jug or flask shaped vesicle, with a cylindrical to weakly conical neck, approximately 25 to 30 % of the total length, and a distinctly flared collarette. Flexure and shoulders distinct and typically well defined separating the chamber from the oral tube; in several specimens this distinction is weak and obscured. Flanks are slightly curved to convex with maximum diameter between the shoulders and just below the chamber midpoint. Chamber ovoid. Basal margin rounded and base convex, and often it will possess a small blunt but distinct mucron at its centre. In rare cases lateral compression of the vesicle wall can give the base a more flattened and slightly truncate appearance. Wall smooth with no

ornament.

Dimensions.

Overall length:	453 (762) 877 μm
Overall width:	139 (316) 394 μm
Oral tube length:	94 (284) 325 μm
Neck width:	69 (176) 237 μm
Aperture width:	98 (187) 231 μm
# specimens measured:	30

Remarks. Material examined by Jenkins (1967), Evitt (1969), Eisenack (1968, 1976) and Achab (1980, 1986a) show that *L. esthonica* has remarkable variation in form and size, more so than most chitinozoan species. Grahn (1980) described individuals with considerable variation in total length (159-1000 μm), maximum width (61-268 μm), neck length (49-512 μm) and width (73-134 μm), and aperture width (48-220 μm) from the early Ordovician of Öland, Sweden. Bockelie (1980), Grahn (1980), Paris (1981) and others, noted that *L. esthonica* seems to exhibit two types of morphological populations in the Arenig and Llanvirn. The older forms, which appear to be restricted to the lower-middle Arenig, are more stout, have a short neck and distinctive chamber while elongated, slender forms have typically been reported from the upper Arenig-lower Llanvirn (Jenkins, 1967; Eisenack, 1968; Grahn, 1980; Paris, 1981).

Examples of atypical *L. esthonica* reported from the Arenig of Baltoscandia and Bohemia with an inconspicuous flexure and smaller overall size led Paris & Mergl (1984) to suggest that these individuals were not conspecific with true *L. esthonica*. Material they

examined from the Klabava Formation displays large variation in size even if distortion of the silhouette due to flattening of the vesicle is accounted for. Consequently, they suggested that typical examples of the species should be restricted to specimens with a short oral tube compared to the overall length of the vesicle ($L_{or}/L < 0.4$) and with a distinct flexure and shoulders consistent with Eisenack's (1955b) holotype; the maximum diameter should also be sizable compared to the vesicle length ($L / D < 4$). It is my opinion that the length to width ratio of true *L. esthonica* should be further restricted to under three (3.0), as all my specimens fall within the range of 2.1-2.9, and within accepted dimensions. Unfortunately, morphometric ratios are often misleading, as elongate individuals with a length to width ratio close to four could easily be confused with forms presently assigned *L. maxima* (Taugourdeau & DeJekhowsky, 1960); in several cases, these elongate forms of *L. esthonica* are likely synonymous with *L. maxima*.

While much of the present material is consistent with the holotype of *L. esthonica*, large size and form variation can be seen throughout the Arenig from the Cow Head Group. Whether this reflects natural biological variability, or is the result of taphonomic or diagenetic processes is currently unclear. Suspecting the later, present populations of *L. esthonica* are not large and diverse enough to go outside established taxonomic nomenclature and justify splitting the species into two or more taxa.

Occurrence. Arenig: Cow Head North (CHN 9.6 B/C), *T. approximatus* Zone; (CHN 9.17 Akz), *T. akzharensis* Zone; (CHN 11.4-B), *P. fruticosus* Zone; St. Paul's Inlet (SPI

55), *T. akzharensis* Zone; (SPI 78), *I. v. maximus* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; (WBN 29), *D. bifidus* Zone.

Stratigraphic Distribution. *Lagenochitina esthonica* is the oldest chitinozoan species reported from Baltoscandia, and it has been recovered from late Tremadocian beds from Skåne, Sweden (Grahn, 1980, 1984) and the Lower Fezouata Formation (Tremadoc) of the Anti-Atlas, Morocco (Elaouad-Debbaj, 1988). While the type material was originally described from the lower part of the middle Glauconite Limestone ($B_{2\alpha}$) of Estonia (Eisenack, 1955b), specimens with characteristic features of the holotype appear to be restricted to the lower-middle Arenigian. Eisenack (1955b) also recovered short forms from the Glaukonitsand (B1), in the *Expansus* Limestone ($B_{3\alpha}$), and the Hunderum (uppermost Arenig to Lower Llanvirn) of Fjäcka, Dalarna, Sweden. Years later he reported the species from the *Vaginatum* Limestone, Kunda stage (Llanvirn) of Hälludden, Öland, Sweden (Eisenack, 1976), and the Latorpian (B_1-lower to upper Arenig) and Volkhovian (B_2-lower to upper Arenig) of Estonia (Eisenack, 1958, 1968, 1976b).

Well preserved examples of *L. esthonica* have also been recovered from the Holy Cross Mountains (Arenig?) of Miedzygórz, Warsaw (Chlebowski & Szaniawski, 1974). Männil (1971) recorded its range as upper Arenig to lower Llanvirn from Estonia, and lower Llanvirn (unillustrated) in the subsurface of the Moscow Syneclise. In North America, Achab (1980, 1986a) reported it from Zones B and C of the Levis Formation (lower-middle Arenig), Quebec, Canada. Typical examples of the species have been reported from the Arenig of the

Novgorod District in Siberia (Obut, 1973) and from the lowermost part of the Valhallfonna Formation, *D. protobifidus* Zone (late Arenig-early Llanvirn) of Ny Friesland, Spitsbergen (Bockelie, 1980) while more elongate, atypical examples have been recovered from the Lower Hope Shales (lower Llanvirn) of the Welsh Borderland (Jenkins, 1967), and the Upper Langevoja (upper Arenig) to Lower Valaste (lower Llanvirn) and Upper Aluoja (lower Llanvirn) of Öland (Grahn, 1980). Rare examples have been recovered from the Goldwyer Formation, Zone 0_4 (lower Arenig) of the Canning Basin, Australia (Combaz & Péniguel, 1972), the lower part of the Pissot Formation among the lower Llanvirnian graptolites at Domfront, Orne, France (Paris, 1981), and the Klabava Formation (Arenig) of Bohemia (Paris & Mergl, 1984).

Lagenochitina maxima (Taugourdeau & DeJekhowsky 1960)

Plate 6, figs. 1-7; Plate 8, figs. 3, 4, 7-9, 13, 14, 19; Plate 9, figs. 2, 4, 5.

Lagenochitina maxima Taugourdeau & DeJekhowsky, 1960, p. 1229, pl. 8, fig. 117; Jansonius & Jenkins, 1978, p. 356, fig. 35, no. 2.

?*Lagenochitina estonica* Jenkins, 1967, p. 463, pl. 74, figs. 4, 5; Grahn, 1980, p. 32, fig. 19, A-D.

Description. Large bottle shaped vesicle with distinct oral tube and chamber. Neck cylindrical to weakly conical, approximately 25 to 30% the total length, and slightly wider at the aperture. Collarette flared. Flexure and shoulders present but smooth and not well

defined. Chamber elongate with straight, subcylindrical flanks that often bear a slight waist-like impression (concavity) just below the shoulders; rarely convex. Maximum width typically occurs at the shoulders with the chamber narrowing slightly but consistently towards the base. Basal margin rounded to inconspicuous and base hemispherical, convex or flat and contains a small basal scar at the centre. Wall smooth.

Dimensions.

Overall length:	720 (926) 1143 μm
Overall width:	242 (289) 320 μm
Oral tube length:	231 (345) 463 μm
Neck width:	133 (162) 196 μm
Aperture width:	136 (195) 234 μm
# specimens measured:	30

Remarks. Western Newfoundland specimens of *L. maxima* (Taugourdeau & DeJekhowsky, 1960) bear a close resemblance to Eisenack's (1931) holotype of *L. cylindrica* with regards to the overall bottle shape and development of a chamber waist or constriction below the shoulders. However, *L. maxima* is typically more then twice the size and posses a more elongated neck with a distinctly flared collarette, which appears to be lacking in *L. cylindrica*.

In their original description of the species, Taugourdeau & DeJekhowsky (1960) emphasized the large size of *L. maxima* which is visible to the naked eye. Its dimensions and shape (subcylindrical chamber, cylindrical neck and flared collarette) are consistent with the Newfoundland material, but otherwise lack a sharp distinction between neck and chamber.

However, this feature can be distorted by preservation and compaction, as was the case with several of the Cow Head [North] specimens. Taugourdeau & DeJekhowsky further added that numerous transverse striations have often been encountered on the necks of several individuals but which were not presently observed either by transmitted light or electron microscopy.

Lagenochitina maxima was originally recorded from the Ordovician (Zone I) of the Sahara. Although rarity of well documented index fossils and key lithostratigraphic units precluded detailed and accurate chronostratigraphy of the region, a 300 metre section of well developed shales and siltstones making up Zones 1 and 2 were interpreted as Ordovician. Whether the presumed age was exclusively Lower Ordovician (Tremadoc and Arenig) or included middle or upper Ordovician units is presently unclear. Jansonius & Jenkins (1978) later compiled an account of chitinozoan biostratigraphy and systematics in which they noted that "large, smooth-walled forms like *L. maxima* were common in the Lower Ordovician (Tremadoc to Arenig) and rare by the Silurian".

Though *L. maxima*'s larger size and subcylindrical chamber, which often possesses a distinct waist below the shoulders, is easy to separate from the shorter more stout form of *L. esthonica* (which has an ovoid chamber with maximum diameter typically at the midpoint), the resemblance between *L. maxima* and elongated forms of *L. esthonica* (Jenkins, 1967; Eisenack, 1968, 1976b; Chlebowski & Szaniawski, 1974; Paris & Mergl, 1984) suggest the possibility that these two forms may be related or even synonymous. Paris & Mergl (1984) suggested that individuals with a length to width ratio of less than four (<1 : 4)

and consistent with the description of *L. esthonica* be restricted to the species. A reduction in this ratio of less than three (2.1-2.9), which is consistent with the Cow Head material, is more in keeping with Eisenack's (1955b) holotype (*L/W*: 2.2-2.7) and eliminates much of the variability that creates an overlap and ambiguity between *L. esthonica* and *L. maxima*.

Occurrence. Tremadoc: Martin Point South (MPS 42-), *A. victoriae* Zone; St. Paul's Inlet (SPN 43-I), *A. victoriae* Zone; **Arenig:** Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; (CHN 11.4-B), *P. fruticosus* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Stratigraphic Distribution. Zone 1 (Ordovician) of the Sahara (North Africa), south of Algeria (Taugourdeau & DeJekhowsky 1960).

Lagenochitina sp. cf. ***L. maxima*** (Taugourdeau & DeJekhowsky 1960)

Plate 6, figs. 8, 9, 16.

Description. Jug or bottle shaped vesicle with subcylindrical to slightly flaring oral tube and collarette making up between 30 and 50 % the vesicle length. Flexure rounded and indistinct, and shoulders present but sloping and poorly defined. Chamber flanks are curved (convex) below the shoulders and narrow slightly towards the base. Maximum diameter occurs at approximately 25 to 40 % the total length from the base. Basal margin rounded to inconspicuous and base convex to hemispherical. Smooth test wall.

Dimensions.

Overall length:	734 (751) 779 µm
Overall width:	197 (198) 201 µm
Oral tube length:	237 (241) 246 µm
Neck width:	98 (99) 100 µm
Aperture width:	94 (95) 97 µm
# specimens measured:	4

Remarks. In overall shape and appearance, specimens of *Lagenochitina* sp. cf. *L. maxima* resemble specimens of *L. maxima*, but the shape of the neck and chamber, and lack of a well-defined flexure and shoulders, seem to distinguish this species.

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Lagenochitina obeligis (Paris 1981)

Plate 6, figs. 11-13; Plate 8, figs. 10-12, 15.

?*Lagenochitina esthonica* Eisenack, 1958, p. 395.

Lagenochitina cf. *baltica* Taugourdeau & DeJekhowsky, 1960, p. 1230, pl. 9, fig. 121; Profichet, 1979, p. 59, pl. 3, fig. 2.

Lagenochitina baltica Taugourdeau & DeJekhowsky, 1960, p. 1230, pl. 9, fig. 122; Benoit & Taugourdeau, 1961, fig. 2.

Lagenochitina brevicollis Rauscher, 1968, p. 56, pl. 3, fig. 9.

Lagenochitina sp. Rauscher, 1968, pl. 3, fig. 10.

Lagenochitina obelixi Paris, 1981, p. 245, pl. 1, figs. 11, 14, pl. 2, figs. 5, 9-11, pl. 3, figs. 11, 13, pl. 4, figs. 16, 17.

Lagenochitina obeligis Elaouad-Debbaj, 1986, p. 77, pl. 1, figs. 6, 10; Grahn, 1992, p. 718, fig. 9, no. 2.

Description. Flask shaped vesicle with cylindrical oral tube distinct from the body, making up 30 to 40% the total length, collarette distinctly flared. Flexure and shoulders both present and distinct. Chamber ovoid to spherical with maximum diameter at the chamber midpoint, and typically longer than the neck. Basal margin inconspicuous and base hemispherical. Wall either smooth or rugose.

Dimensions.

Overall length:	511 (627) 789 μm
Overall width:	237 (298) 373 μm
Oral tube length:	183 (266) 338 μm
Neck width:	127 (174) 197 μm
Aperture width:	138 (193) 246 μm
# specimens measured:	9

Remarks. Specimens of *L. obeligis* (= *L. obelixi*, Paris 1981, p. 245) from western Newfoundland are twice the size of Paris' (1981) holotype but are consistent with the form of the species and ratios of length to width. An important diagnostic feature of the species is that the body is longer than the neck. Grahn (1992) pointed out that for the Brazilian specimens the shape of the chamber varies from spherical to ovoid and is either smooth or

rugose, with a distinct flexure separating the neck from the body which then terminates in a distinctly flared collarette; in rare cases the neck may be up to half the total length. While *L. obeligis* resembles *Sphaerochitina sphaerocephala* (Eisenack, 1932), and their size ranges often overlap, *S. sphaerocephala* typically shows more variability in form, its neck is much more elongate and its surface is covered with small spines or microverrucae (Paris, 1981). Further, *S. sphaerocephala* has only been documented from upper Silurian strata. Although *L. esthonica* (Eisenack, 1955b) and *L. baltica* (Eisenack, 1931) can be deformed (using computer graphics) to resemble *L. obeligis*, they both have less spherical chambers and broader bases which are typically convex to flattened; *L. baltica* also has a straight, indistinct collarette. *Lagenochitina prussica* (Eisenack, 1931) has often been confused with *L. obeligis* but its oral tube is very short, almost perfectly cylindrical and lacks a distinct collarette.

With the dimensions of my material well above Paris' holotype, the certainty of its identity may be in question, even though they are consistent with all other aspects of its morphology and show tangible differences from other lagenochitinids and sphaerochitinids alike. Consequently, I propose that the size range for the species *L. obeligis* be extended to include those individuals presently identified from the Cow Head Group, western Newfoundland which show strong affinity for Paris' (1981) holotype from southwestern Europe.

Occurrence. Arenig: Cow Head North (CHN 9.17 Akz), *T. akzharensis* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis*

Zone; (WBN 29), *D. bifidus* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone.

Stratigraphic Distribution. Massif Armoricain, in the Grès Armoricain, and the extreme base of the Pissot Formation (Arenig-Llanvirn), France (Paris, 1981). In Portugal the species has been recovered from the lower part of the Cacemes Formation (Arenig-Llanvirn) (Paris, 1981). In the Anti-Atlas, Maroc, it has been recovered from the Tachilla Formation of upper Arenigian to lower Llanvirnian age (Elaouad-Debbaj, 1984), and from the Solimões Basin, Benjamin Constant Formation (middle Arenig-lower Llanvirn) of Brazil (Grahn, 1992).

Lagenochitina sp. cf. ***L. ovoidea*** (Benoit & Taugourdeau 1961)

Plate 6, figs. 14, 15; Plate 7, fig. 16; Plate 8, fig. 6.

Description. Lagenoid vesicle with subcylindrical oral tube that flares slightly towards the aperture, and makes up about a third of the total vesicle length. Collarette absent, flexure and shoulders present but smooth and rounded and weakly defined. Chamber is elongate and distinctly ovoid in shape with maximum diameter just below the shoulders. Basal margin inconspicuous and base bluntly ogival (=subogival). Overall the vesicle wall is smooth, but one of the lateral margins appears to possess bumps or ridges, likely the result of pyrite crystal growth. Ornament absent.

Dimensions.

Overall length:	619 (649) 680 μm
Overall width:	256 (273) 289 μm

Oral tube length:	187 (193) 199 μm
Neck width:	145 (169) 193 μm
Aperture width:	162 (183) 204 μm
# specimens measured:	4

Remarks. While *Lagenochitina* sp. cf. *L. ovoidea* closely resembles Benoit & Taugourdeau's (1961) *Lagenochitina ovoidea*, it is more than three times the size of the holotype and its features are more pronounced (eg. chamber more distinctly ovoid and neck more offset from the chamber). Unfortunately, the rarity of *Lagenochitina* sp. cf. *L. ovoidea* (a pair of specimens) does not permit a critical comparison of populations and any species level assignment would be contentious at best. Instead, the nomenclature is left open with the designation [cf] to reflect its likely affinity with the holotype

Occurrence. Arenig: St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Lagenochitina tumida (Umnova 1969)

Plate 4, fig. 26.

Lagenochitina tumida Umnova, 1969, p. 338, pl. 2, figs. 33, 34; Grahn & Afzelius, 1979, p. 121, fig. 3; Grahn, 1980, p. 34; fig. 19, E-G.

Description. Lagenoid vesicle with a subspherical to ovoid chamber and short cylindrical oral tube making up one third of the total length. Flexure distinct, shoulders steep and poorly

defined. Flanks curved with maximum diameter at or just below the vesicle's midpoint. Basal margin inconspicuous and base bluntly ogival. A rounded basal process may also occur. Vesicle wall smooth.

Dimensions.

Overall length:	423 μm
Overall width:	211 μm
Oral tube length:	88 μm
Neck width:	96 μm
Aperture width:	94 μm
# specimens measured:	1

Remarks. The individual here identified as *L. tumida* is consistent with Umnova's (1969) holotype, though slightly larger, and is almost identical to those illustrated by Grahn (1980). Its small size, short, narrow cylindrical oral tube and ovoid chamber appears to distinguish it from other lagenochitind species. Years after Umnova's (1969) work, Combaz & Péniguel (1972) described a new species which they also gave the name *L. tumida* (p. 146; pl. 4, fig. 8). Aside from its stout form and small dimensions, the latter bears little resemblance to Umnova's holotype. *Lagenochitina tumida* of Combaz & Péniguel (1972) rather resembles *L. brevicollis* (Taugourdeau & DeJekhowsky, 1960) which, however, has a more spherical chamber and flat to convex base. Finger (1982) later regarded *L. tumida* of Combaz & Péniguel (1972) as a "primary junior homonym" of Umnova's (1969) binomial, and gave it the new designation, *Lagenochitina combazi*.

Paris & Mergl (1984) considered *L. tumida* to be synonymous with Taugourdeau &

DeJekhowsky's (1960) *Desmochitina bulla* (pl. VI, fig. 87-holotype; pl. VII, fig. 88) and Benoit & Taugourdeau's (1961) *D. urceolata* (pl. 3, figs. 29, 30). While the resemblance between *D. bulla* and *D. urceolata* suggests an affinity, they are both much more spherical, have a basal process or mucron and a distinctly flared collarette sitting on a very short oral tube. Paris & Mergl (1984) further noted that *D. bulla* is highly polymorphic with large variations of the size. I concede the possibility that *L. tumida* and *D. bulla* are conspecific. However, *L. tumida* from western Newfoundland and those illustrated by Grahn (1980) show that these two forms are almost identical. The sole specimen identified in this study as *L. tumida* is much more elongate and ovoid, resulting in a silhouette that falls well outside the strict diagnosis of the spherical genus *Desmochitina*.

While they acknowledged that the material examined from the Baltic (Öland) by Grahn (1980) has a more ovoid shape, Paris & Mergl (1984) believed that the Baltic specimens and their own specimens from the Klabava Formation, Bohemia, were conspecific. In their view, Umnova's (1969) illustrations (pl. 2, figs. 33, 34) of *L. tumida* were too poor to allow a conclusive comparison with their specimens. However, Umnova at least showed that the shape of the species is more consistent with *Lagenochitina* than *Desmochitina*. Paris & Mergl's (1984) contention is not accepted here, as the specimens identified as *L. tumida* appear too dissimilar to their material even if polymorphic variation is taken into account. Consequently, the diagnosis and descriptions of the species by Umnova (1969) and Grahn (1980) are followed here.

Occurrence. Arenig: Western Brook North (WBN 18-A), *T. akzharensis* Zone.

Stratigraphic Distribution. Volkov (Upper Arenig), Moscow Syneclise, former U.S.S.R. (Umnova, 1969); Lower Hunderum (uppermost Arenig) of Öland (Grahn, 1980).

Lagenochitina sp.

Plate 6, fig. 10.

Description. Jug or bottle shaped (lagenoid) vesicle with extremely long oral tube making up two thirds the total vesicle length. Neck cylindrical with a slight lateral swelling at about half the tube length. Aperture straight, collarette indistinct. Both flexure and shoulders present, but well rounded and poorly defined. Chamber ovoid to spherical with maximum diameter at its midpoint. Basal margin inconspicuous and base convex to rounded. Wall smooth.

Dimensions.

Overall length:	1173 µm
Overall width:	276 µm
Oral tube length:	734 µm
Neck width:	207 µm
Aperture width:	143 µm
# specimens measured:	1

Remarks. While *Lagenochitina* sp. resembles the paratype of *L. grandis* (Taugourdeau & DeJekhowsky, 1960), it is more than twice the size of the holotype and lacks a conical

chamber and flat base which are diagnostic features of the species. Further, *Lagenochitina* sp. resembles some of the more elongated examples of *Sphaerochitina sphaerocephala* (Eisenack, 1932), but its large dimensions and distorted shape do not permit a specific identification.

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone.

Subfamily CYATHOCHITINIDAE Paris 1981

Genus *Cyathochitina* Eisenack 1955b, emend. Paris 1981,

emend. Paris, Grahn, Nestor & Lakova 1999

Type species: *Conochitina campanulaeformis* Eisenack 1931

Remarks. The emended diagnosis of Paris (1981) defines the genus *Cyathochitina*, as "chitinozoa with subcylindrical to conical chamber; oral tube sometimes difficult to differentiate from the chamber; shoulders absent or discrete; flexure usually well defined; basal margin coincides with the maximum diameter of the vesicle; skirt or membranous carina at the aboral pole around the basal margin; base flat or convex; mucron absent; aperture straight to slightly flared; test surface smooth, or slightly pitted." Until Paris (1981) emended the definition of the genus by transferring the "trumpet-shaped" vesicles with an aborally directed carina within the lateral margin to the genus *Laufeldochitina* (Paris, 1981), the description of the genus *Cyathochitina* has changed very little since Eisenack (1955b) erected it. Recently, however, Paris *et al.* (1999) further emended this definition by

transferring conical individuals without a conspicuous flexure to the new genus *Hyalochitina* (Paris & Grahn, *in* Paris *et al.*, 1999). This latest emendation by Paris *et al.* is adopted in the following account (see Text-fig. 4.1).

Cyathochitina calix (Eisenack 1931)

Plate 4, figs. 4-9.

Conochitina calix Eisenack, 1931, p. 87, pl. 2, fig. 3; ?Eisenack, 1939, p. 137, pl. B, figs. 4, 5.

Cyathochitina calix Eisenack, 1948, figs. 3, 4?; Eisenack, 1958, p. 397, pl. 2, figs. 26, 27; Eisenack, 1962a, p. 296, pl. 14, figs. 3, 4; Eisenack, 1965, p. 128, pl. 11, figs. 1, 2; Eisenack, 1968, p. 168, pl. 31, figs. 8, 9, 27; ?Jenkins, 1967, p. 456, pl. 71, figs. 5-7; Rauscher & Doubinger, 1967a, p. 474, pl. 2, fig. 1; Umnova, 1969, pl. 1, fig. 37 (non figs. 36, 38); ?Rauscher, 1970, p. 119, pl. 1, figs. 4, 5; ?Atkinson & Moy, 1971, pl. 1, figs. N-Q; ?Tynni, 1975, p. 48, fig. 46a; Eisenack, 1976b, p. 187, pl. 2, fig. 3; Grahn, 1980, p. 23, fig. 14, A-G; Grahn, 1981a, p. 30, fig. 11, A, D; Grahn, 1981b, p. 15, fig. 5, A-D; Paris, 1981, p. 288, pl. 8, figs. 5, 7-9, 11, 13, 16, pl. 10, fig. 19?; Grahn, 1982a, p. 34, fig. 14 A-D; Grahn, 1984, p. 16, pl. 2, figs. B-D; Grahn & Bergström, 1984, p. 114, pl. 2, figs. F-H; Bergström & Grahn, 1985, pl. 2, figs. F-H; Grahn & Miller, 1986, p. 395, fig. 7, nos. 3, 4; Miller, 1996, pl. 3, fig. 2.

Cyathochitina cf. *calix* Taugourdeau & DeJekhowsky, 1960, p. 1224, pl. 5, fig. 66;

Taugourdeau, 1961, p. 141, pl. 3, fig. 40.

Description. Conical to subcylindrically shaped vesicle with very short cylindrical to weakly conical neck, about 30-35% the total length, which merges almost indistinguishably with the chamber. Collarette straight and indistinct, flexure weakly defined. Flanks straight to only slightly convex and widen to maximum diameter at the base, which is almost twice the aperture diameter. Basal margin sharp, with a carina that projects laterally and slightly aboralward; carina may be indistinct. Base flat to only slightly convex, rarely concave. Wall smooth.

Dimensions.

Overall length:	384 (559) 636 μm
Overall width:	147 (178) 195 μm
Oral tube length:	--
Neck width:	--
Aperture width:	96 (114) 123 μm
# specimens measured:	15

Remarks. *Cyathochitina calix* is distinguished from other common cyathochitinids, particularly *Cyathochitina campanulaeformis* (Eisenack, 1931), in having a more slender and elongate form, and a less pronounced distinction between the oral tube and chamber. Though *C. calix* superficially resembles several forms of *Hyalochitina hyalophrys* (formerly *Tanuchitina*, Eisenack, 1959), it typically has more convex flanks and a weak flexure, while its carina is more offset from the basal margin. The majority of my western Newfoundland specimens have a length to width ratio of 2:1 or greater. Grahn (1980) noted that only about

5% of the *C. calix* specimens from Öland fall below this ratio, while Jenkins' (1967) Welsh Borderland specimens are much stouter with a ratio of 1.5-2.1:1.

Occurrence. Arenig: Cow Head North (CHN 9.17-Akz), *T. akzharensis* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone; (WBS 28-A), *I. v. lunatus* Zone; (WBS 34), *I. v. maximus* Zone; (WBS 52-A), *U. austrodentatus* Zone; (WBS 62), *U. austrodentatus* Zone.

Stratigraphic Distribution. Until fairly recent, *Cyathochitina calix* was only known from European strata. Eisenack (1931) first described the holotype from a light-grey limestone of unknown age in Estonia, and later he recovered specimens from the Herscheider Shale (Caradoc?) of Westphalia, West Germany (Eisenack, 1939). In the decades following, Eisenack described the species from the Glaukonite Limestone and the Volkhovian (B_2-lower to upper Arenig) to Aserian (C_{1a}-upper Llanvirn) of Estonia (Eisenack, 1958, 1962a, 1968), the Hunderumian (uppermost Arenig-lower Llanvirn) of Dalarna, Sweden (Eisenack, 1962a); the *Expansus* Limestone of Dalarna and Öland, and the *Vaginatum* Limestone of Öland (both B_3-upper Arenig to lower Llanvirn), Sweden (Eisenack, 1962a, 1968, 1976a). Grahn reported *C. calix* from the Upper Langevojan to Lower Valastean (upper Arenig-lower Llanvirn) and Upper Aluojan (lower Llanvirn) and Seby (upper Llanvirn) to the Lower Dalby Limestones of Öland, Sweden (Grahn, 1980, 1981a); the Gullhögen Formation (lower Llandeilo) to Upper Dalby Limestones, Västergötland, Sweden (Grahn, 1981b), and the Arenigian to late Caradocian strata in Baltoscandia (Grahn, 1982a). In Gotland he described the species from

the Upper Kukrusean to Skagen and Rakverean (lower Caradoc-upper middle Caradoc) (Grahn, 1982a).Grahn (1984) recovered specimens from the Volkhov Stage (upper Arenig) from Tallinn, northern Estonia. The species has also been recovered from Zones 2 and 3 (Ordovician-Gotlandien) of the Sahara, south of Algeria (Taugourdeau & DeJekhowsky, 1960), the Silurian of Aquitaine (Taugourdeau, 1961), the Ordovician of the Sahara (Benoit & Taugourdeau, 1961), the Hope Shales (lower Llanvirn), Welsh Borderland (Jenkins, 1967), and the subsurface Volkhovian to Kundan (B_2 to B_3-lower Arenig to lower Llanvirn) of the Moscow Syneclise, former U.S.S.R. (Umnova, 1969).

Previously *Cyathochitina calix* has been poorly documented from North America but has been recorded from the base of the Arenig to uppermost Llandeilo of North-Central Florida, U.S.A. (Andress *et al.*, 1969); the Upper Lenoir Limestone (Llanvirn-Llandeilo) at Marble Hollow and Pratt Ferry, Alabama, and the Chickamauga Limestone (upper Llandeilo-early Caradoc) at Red Mountain, Georgia, U.S.A. (Grahn & Bergström, 1984); and the Bromide Formation (upper Llandeilo-Caradoc) in the Mountain Lake Member of Oklahoma, U.S.A. (Grahn & Miller, 1986).

Cyathochitina dispar (Benoit & Taugourdeau 1961)

Plate 4, figs. 1-3

Cyathochitina dispar Benoit & Taugourdeau, 1961, p. 1408, pl. 3, figs. 22-28; Martin, 1969, p. 101, pl. 1, figs. 3, 15, pl. 2, fig. 30; McClure, 1988, pl. 3, fig. 4.

?*Cyathochitina dispar* subsp. *verrucata* Taugourdeau, 1961, p. 142, pl. 3, figs. 44, 45, pl. 6, fig. 85.

Cyathochitina dispar subsp. *verrucata* Taugourdeau, 1965, p. 469, pl. 2, fig. 37.

?*Conochitina lepida* Jenkins, 1967, p. 452, pl. 70, figs. 2, 3.

Description. Bell-shaped, or campanulate vesicle with short, cylindrical oral tube (with straight collarette) approximately one third the vesicle length. Flexure present but poorly defined, shoulders indistinct. Below the oral tube the flanks are slightly curved and widen to a maximum diameter at the base. Basal margin sharp, with a distinct but small skirt-like ridge or carina which appears as a spine that projects out more laterally than aborally. Base convex, bulging down as far as, or slightly below the carina. Wall smooth.

Dimensions.

Overall length:	306 (374) 409 µm
Overall width:	158 (177) 190 µm
Oral tube length:	--
Neck width:	--
Aperture width:	94 (98) 102 µm
# specimens measured:	10

Remarks. *Cyathochitina dispar* was first reported and described by Benoit & Taugourdeau (1961) from the Lower-middle Ordovician of the Sahara. The Cow Head specimens agree with the dimensions of the species' holotype but do not exhibit as pronounced a curved (convex) flank, and their maximum diameter is closer to the base rather than just above the basal margin. Superficially, *C. dispar* resembles some *Cingulochitina* species, particularly

C. serrata and *C. ervensis* as illustrated by Paris (1981). However, these species are less than half the size of the western Newfoundland material and characteristically possess a distinct basal mucron, and resort under the family Desmochitinidae (subfamily Pterochitinae). Both *Cingulochitina* species are currently only found throughout the Silurian and Devonian. While the majority of cyathochitinids extend into the Upper Ordovician and beyond, Paris (1981) illustrated *C. dispar* as a lower and middle Arenig evolutionary precursor to the more common cyathochitinids, particularly *C. campanulaeformis* and *C. kuckersiana*, of Middle and Upper Ordovician age, respectively.

Occurrence. Arenig: Western Brook South (WBS 34), *I. v. maximus* Zone.

Stratigraphic Distribution. Subspecies "*verrucata*" from the Silurian of Aquitaine (Taugourdeau, 1961); Ordovician (middle Arenig?) of the Sahara (Benoit & Taugourdeau, 1961); rare in the Upper Ordovician of Iowa, Oklahoma (Taugourdeau, 1965); upper Arenig to lower Llanvirn (Huy-4, SAR-72.305), Condroz, Belgium (Martin, 1969); Tabuk Formation, Hanadir Shales (Llanvirn), northwest Arabia (McClure, 1988).

Cyathochitina sp.

Plate 4, figs. 10-14.

Description. Campanulate or jug-shaped vesicle with distinct oral tube and chamber. Neck cylindrical to weakly conical, flaring very slightly at the aperture and makes up about 25-30% the total length. Flexures and shoulders are both present but rounded and weakly

defined. Chamber flanks are curved and widen so that maximum diameter occurs in the lower half of the vesicle approximately 50-60% the total length, below which they narrow slightly towards the base. Basal margin sharp and possess a narrow but smooth carina which projects aborally and laterally giving the margin a pointed appearance; in several individuals the margin is more blunt as a distinct carina is not present and was likely broken off during preservation. Base flat to slightly concave, vesicle wall smooth.

Dimensions.

Overall length:	439 (526) 587 µm
Overall width:	217 (261) 291 µm
Oral tube length:	123 (130) 241 µm
Neck width:	94 (123) 158 µm
Aperture width:	100 (118) 140 µm
# specimens measured:	9

Remarks. *Cyathochitina* sp. is similar to Eisenack's (1931) description of *Cyathochitina campanulaeformis* but is slightly larger; a discernible carina around the basal margin was likely destroyed during preservation. However, the ratio of length to width of approximately 1.5:1 is consistent with the holotype. Although the stratigraphical range of *C. campanulaeformis* falls within that of the present study, well preserved individuals bearing crucial diagnostic features are lacking. Consequently, the nomenclature must remain open.

Occurrence. Arenig: Cow Head North (CHN 9.17 Akz), *T. akzharensis* Zone; St. Paul's Inlet (SPI 55), *T. akzharensis* Zone; Western Brook North (WBN 18-A), *T. akzharensis* Zone; Western Brook South (WBS 23-C), *D. bifidus* Zone.

CHAPTER 5: CHITINOZOAN BIOSTRATIGRAPHY

5.1. Previous Research

Since their discovery in 1931, hundreds of reports have been written on chitinozoans, yet until fairly recently, relatively few have used them in producing a regional biostratigraphic framework. In the decades immediately following Eisenack's early work (1931, 1932, 1934, 1937), their biostratigraphic potential was largely ignored (Paris, 1996). Chitinozoans first became useful as a stratigraphic tool during the late 1950's when oil companies began exploring and actively drilling lower Paleozoic strata in North Africa (DeJekhowsky, 1958). Unfortunately, during these early works, independent age calibrations (e.g. using conodont or graptolite faunas) from other sections were not yet available, and only very broad chronostratigraphic units were documented (Taugourdeau & DeJekhowsky, 1960). During the early 1960's, studies of well-established stratigraphic sections in Estonia (Eisenack, 1958, 1962c) and Gotland (Eisenack, 1962b, 1964; Taugourdeau & DeJekhowsky, 1964) and the results of "comprehensive" closely spaced drill core data (Benoit & Taugourdeau, 1961; Taugourdeau, 1961), began to suggest the potential of chitinozoans for regional correlations.

The first reports of chitinozoan stratigraphy appeared in the early 1970's after a new approach of quantifying more closely spaced samples throughout continuous well-known sections (Laufeld, 1967; Taugourdeau *et al.*, 1967) was implemented. During this time

sufficient material existed to allow correlation of stratigraphically similar sections, and this lead to the development of the first useful biostratigraphic ranges for Ordovician chitinozoa (Jansonius, 1970; Männil, 1971; Combaz, 1972; Combaz & Péniguel, 1972; Urban, 1972; Paris, 1976; Jenkins & Legault, 1979).

During the 1980's and into the 1990's, chitinozoan reports began to focus on the analysis of stratigraphically important sections (those that have been well dated by other fossils, including graptolites and conodonts) in an attempt to identify assemblages or taxa that could characterize the different graptolite and conodont zones and help with the resolution of dating problems where "holes" existed in the faunal record (Achab, 1989). Early in the 1980's, the first detailed biostratigraphical reports were published, including those from eastern Canada (Achab, 1981, 1986a,b, 1989), southwestern Europe (Paris, 1981), the east Baltic (Nõlvak, 1980), China (Hou & Wang, 1982), Sweden (Grahn, 1982c), the U.S. (Bergström & Grahn, 1985), and Morocco (Elaouad-Debbaj, 1988). During the early 1990's, additional biostratigraphical reports from Brazil (Grahn, 1992), and North Africa (Oulebsir, 1992a, b) appeared, including an account by Paris (1992) who began applying chitinozoans to long-distance Ordovician correlations.

Formal biozonations have now been proposed for the Ordovician chitinozoans of eastern Canada (Achab, 1989), the Northern Gondwana Domain (southwestern and central Europe, the Middle-East, northern Africa and Florida: Paris, 1990), and Baltoscandia (Scandinavia, the East Baltic, northeast Poland and Podilia: Nõlvak & Grahn, 1993).

Recently, Paris (1996) produced a compilation of regional chitinozoan biozonations using a number of widely distributed taxa, and correlated equivalent sections of Laurentia, Northern Gondwana and the Baltic region.

5.2. Chitinozoan Assemblages

Out of sixteen samples from six sections across the Lower Ordovician Cow Head Group, thirty-two (32) named species of well-preserved chitinozoans, including an additional twenty-two (22) of uncertain specific affinity, from nine genera were identified (Table 4.1). Overall, two genera dominate (> 80%) the fauna: *Conochitina* and *Lagenochitina*. Text-Figure 5.7 presents a broad synthesis of important Lower Ordovician chitinozoan assemblages from North America (Achab, 1980, 1982, 1986a), Europe (Paris, 1981), North Africa (Combaz, 1967; Poumot, 1968; Benoit & Taugourdeau, 1961; Elaouad-Debbaj, 1984, 1988), the Baltic (Eisenack, 1958, 1968; Grahn, 1980, 1984), Spitsbergen (Bockelie, 1980), Russia (Umnova, 1969, 1981) and Australia (Combaz & Péniguel, 1972; Achab & Millepied, 1980). After a review of some two dozen papers, certain species of chitinozoans exhibit clear geographic and stratigraphic trends in Tremadoc and Arenig sections, while others form recognizable associations that are potentially useful in long distance correlations.

5.2.1. Tremadoc

Combaz (1967) described the first Tremadoc chitinozoans from the El Gassi Sandstone of the Algerian Sahara, viz. *Eremochitina baculata* var. *grandis* and *E. tremadoca*. Two years later, Umnova (1969) described the chitinozoans *Rhabdochitina gallica, Lagenochitina pervulgata* and *Conochitina communis* from the Tremadoc Leetse horizon of the Moscow Syneclise. Over a decade later, Umnova (1981) refined her earlier work and cited *Conochitina incompta* and *Cyathochitina laticollam* in association with *Lagenochitina esthonica* (Eisenack, 1955b), *Conochitina brevis* (Taugourdeau & DeJekhowsky, 1960) and *Lagenochitina pervulgata*, as constituting the first Tremadoc chitinozoan assemblage of the area. Within the Tremadoc of Skåne, Sweden, Grahn (1980) described and illustrated a large elongated specimen of *Lagenochitina esthonica*? as the oldest known chitinozoan species from Baltoscandia (see Text-fig. 5.7). A comparison of this species with Newfoundland specimens attributed to *L. maxima* (Taugourdeau & DeJekhowsky, 1960) reveals such a close resemblance that the two taxa are quite likely conspecific. This match could indicate a wider distribution of Baltic and western Newfoundland assemblages that has not previously been documented.

More recently, Elaouad-Debbaj (1988) described a suite of Tremadoc chitinozoans from the Lower Fezouata Formation of the Anti-Atlas in southern Morocco, which included *Lagenochitina ventriosa* (Achab, 1980), *L. esthonica*? (Eisenack, 1955b), and *Conochitina poumoti* (Combaz & Péniguel, 1972) in association with a new species of lagenochitinid, *L.*

destombesi (Elaouad-Debbaj, 1988). While previous attempts to recover chitinozoans from well-dated Tremadoc sections in Quebec have not been fruitful, Tremadoc sections of the Cow Head Group have yielded a well-preserved fauna of *Amphorachitina conifundas* (Poumot, 1968), *Amphorachitina* sp. (Poumot, 1968), *Lagenochitina destombesi* and *L. maxima*, which has important implications for the geology of the Cow Head Group. The present Newfoundland assemblage has species in common with similar dated assemblages of north Africa (Benoit & Taugourdeau, 1961; Poumot, 1968; Elaouad-Debbaj, 1984, 1988), and is comparable to an assemblage identified by Williams *et al.* (1999) from the upper Tremadoc (*A. victoriae* Zone) and lower Arenig (*T. approximatus* Zone) of the Ledge Section (CHN) on the Cow Head Peninsula.

5.2.2. Arenig

The Arenig is characterized by rapid diversification of chitinozoan taxa; consequently, it has been the subject of numerous reports. Arenig chitinozoans are known from virtually every continent, which makes long-distance correlations between biogeographic provinces possible.

The oldest report of a lower Arenig microfauna is from the lower shaly-sandy complex of the Sahara where Benoit & Taugourdeau (1961) described an assemblage of *Conochitina symmetrica* (Taugourdeau & DeJekhowsky, 1960), *Conochitina decipiens* (Taugourdeau & DeJekhowsky, 1960), *Eremochitina baculata* (Taugourdeau &

DeJekhowsky, 1960) and *Lagenochitina ovoidea* (Benoit & Taugourdeau, 1961) (Text-fig. 5.7). Combaz & Péniguel (1972) later described an assemblage from the Nambeet Formation of the Canning Basin, Australia which consisted of *C. symmetrica*, *L. ovoidea*, *L. combazi* (Finger, 1982), *C. langei* (Combaz & Péniguel, 1972) and *Eremochitina* sp. In Bohemia, Paris & Mergl (1984) recovered *C. symmetrica*, *C. decipiens* and *L. esthonica* from the lower Klabava Formation, which was very similar to assemblages described from both Quebec (Achab, 1980, 1982, 1986a) and western Newfoundland (this study). In each case the appearance of *C. symmetrica* coincided with a change from the Tremadoc to the base of the Arenig, which makes it an extremely useful index species that corresponds with the *Tetragraptus approximatus* (early Arenig) and equivalent zones. The co-occurrence of *C. decipiens* in African, European and North American assemblages gives further character to the widespread distribution of diagnostic species, strengthening the affinity of North American sections.

Although *Eremochitina baculata grandis* has been associated with *C. symmetrica* in the Sahara, it has not been encountered in Quebec or Bohemia. On the other hand, *L. esthonica* has been found in association with *C. symmetrica* in Bohemia, Quebec and western Newfoundland.

While the microfaunal associations of the *Didymograptus* and subsequent [younger] zones are more difficult to interpolate, *E. baculata brevis* (Benoit & Taugourdeau, 1961) appears to be a relatively common element within the European (Paris, 1981), Saharan and

Moroccan (Elaouad-Debbaj, 1984) assemblages. Likewise, *Lagenochitina obeligis* (Paris, 1981) seems to be a species that is more common in middle Arenig assemblages of France (Paris, 1981), Brazil (Grahn, 1992), western Newfoundland (this study), and the upper Arenig of Morocco (Elaouad-Debbaj, 1984).

Within similar age strata of Australia, Spitsbergen, Quebec and Newfoundland, a number of middle Arenig elements are common, including *Conochitina langei*, *C. poumoti* (Combaz & Péniguel, 1972) and *C. kryos* (Text-fig. 5.7). The presence of both *L. boja* (Bockelie, 1980) and *L. combazi* in these sections adds an interesting and possibly important biostratigraphic character. However, the rarity of *L. combazi* within this study and the uncertain identification of Quebec specimens (*Lagenochitina* cf. *L. combazi*), suggests more work is required to assess their biostratigraphical potential.

In Baltoscandia, Eisenack (1968) identified a lone specimen of *Lagenochitina ovoidea* from older sections of the Latorp B_I stage. As this species had also been recovered from Arenig sections of the Sahara (Benoit & Taugourdeau, 1961) and Australia (Combaz & Péniguel, 1972), Achab (1986a) recognized this taxon as having a cosmopolitan distribution. The presence of a possibly conspecific taxon (*Lagenochitina* cf. *L. ovoidea*) within the *Tetragraptus akzharensis* Zone of western Newfoundland (this study) could indicate a potentially important lower Arenig marker.

Within the Baltic region, *Cyathochitina calix* is a very common and characteristic element of the Volkov (B_{II}) Stage, one that has been described from equivalent sections of

the Russian Platform and the Sahara (Text-fig. 5.7). Its presence throughout the Arenig of western Newfoundland corresponds with the earliest occurrence of the species at the base of the Arenig in south-central Florida, U.S.A. (Andress *et al.*, 1969), and could indicate another potentially useful species for comparing North American and Baltic sections.

Paris & Mergl (1984) described a Bohemian fauna containing *Desmochitina bulla*, earlier reported from the Sahara (Benoit & Taugourdeau, 1961), Morocco (Elaouad-Debbaj, 1984), the Russian Platform (Umnova, 1969), and Sweden (Eisenack, 1958), and pointed out its stratigraphic utility for identifying the upper Arenig (*Didymograptus hurundo* Zone).

In Australia, Combaz & Péniguel (1972) described an assemblage of *Conochitina langei* and *C. poumoti* from the uppermost Arenig, Zone O_3, of the Thangoo Formation, just before the appearance of *C. subcylindrica* (Combaz & Péniguel, 1972), which characterized the lowermost Llanvirn, Zone O_4, of the Goldwyer Formation. In Quebec, Achab (1982) described a similar assemblage of *C. langei*, *C. poumoti* and *Belonechitina pirum* (Achab, 1982) from Zone D of the Levis Formation which corresponds with the *D. hurundo* Zone of the uppermost Arenig. The following year she described the same assemblage, which also included *C. subcylindrica*, from the lower Llanvirn of the Table Head Formation of western Newfoundland (Achab, 1983). Within the Cow Head Group of western Newfoundland (this study), similar assemblages, including individuals of *C. langei*, *C. poumoti*, *C. kryos* and *L. esthonica*, were commonly present throughout middle and upper Arenig sections, illustrating a close affinity with the microfaunas of Quebec and Australia. While *B. pirum* has not been

positively identified within the Cow Head Group, *C. subcylindrica* was recovered from upper-middle Arenig sections (*D. bifidus* to *I. v. maximus* zones) of Western Brook Pond, suggesting its stratigraphic use may not be limited to lower Llanvirn strata as Achab (1986a) had indicated.

The faunal assemblages documented for the Arenig of western Newfoundland establish a strong correlation with equivalent sections from Quebec and Australia. The occurrence of potentially useful stratigraphic markers such as *Lagenochitina boja*, *Lagenochitina combazi*, *Lagenochitina* sp. cf. *L. ovoidea*, *Cyathochitina calix* and *Conochitina brevis* suggests that Newfoundland shares an affinity with other paleogeographic provinces of North Africa (Benoit & Taugourdeau, 1961; Elaouad-Debbaj, 1984; Paris & Mergl, 1984), Europe (Paris, 1981), Russia (Umnova, 1969) and Baltica (Eisenack, 1968; Grahn, 1980, 1984). The additional occurrence of taxa such as *Lagenochitina* sp. cf. *L. baltica* (Eisenack, 1931), *Conochitina subcylindrica* and *Conochitina turgida* (Jenkins, 1967), which have been cited as useful indicators of Llanvirn strata (Achab, 1980, 1983; Paris, 1981) would appear to diminish their relative biostratigraphic importance.

5.3 Chitinozoan Zonation

The zonal scheme presented here is built on previous chitinozoan zonations that have been established for the Lower Ordovician system of Laurentia (Achab, 1986a, 1989) and

Northern Gondwana (Europe; Paris, 1990, 1996). While the present work largely refines Achab's (1989) eastern Canadian zones, three new [*] biozones have been proposed (see Text-fig. 5.9).

5.3.1. **Amphorachitina conifundas* Zone

Paris (1990) developed the first detailed chitinozoan zonation for the Ordovician system of Northern Gondwana which included Tremadoc faunal biozones. Although previous attempts to extract chitinozoans from well-dated Tremadoc rocks in Quebec have been futile (Achab, 1989), well-dated upper Tremadoc rocks (Williams & Stevens, 1988, 1991) of the *A. victoriae* graptolite zone from St. Paul's Inlet (SPI <9.44) and Martin Point South (MPS <42-f) of this study have yielded *Amphorachitina conifundas*, *Amphorachitina* sp., *Lagenochitina destombesi* and *L. maxima*.

Elsewhere, the two Tremadocian total-range biozones *Amphorachitina conifundas* and *Lagenochitina destombesi* of Paris (1990) are distinct and do not overlap. In Newfoundland, however, these two index species occur in the same assemblage. Paris (1990) noted that the Bohemian assemblage of *A. conifundas* is monospecific, but in Algeria it may coexist with *Conochitina* spp. and elongate forms of *L. esthonica*; the latter I suspect may be equivalent to forms of *L. maxima* reported in this study. Within the Cow Head Group, *L. destombesi* extends from the upper Tremadoc into the lower part of the Arenig, *Isograptus victoriae lunatus* Zone, which is younger than the age range (lower Tremadoc) of the

holotype given by Elaouad-Debbaj (1988) from the Lower Fezouata Formation (lower-middle Tremadoc) of the Anti-Atlas, southern Morocco. Unfortunately, exposed lower Tremadoc rocks within the Cow Head Group are relatively unfossiliferous (Williams, pers. comm.) and to date have not yielded chitinozoans which would be useful in identifying a separate *Lagenochitina destombesi* biozone. However, the presence of *L. destombesi* and *A. conifundas* at Cow Head show a broader distribution of Northern Gondwanan faunas than previously documented. The co-occurrence of *A. conifundas*, *L. destombesi* and *L. maxima* may therefore indicate a biostratigraphically useful assemblage for recognizing upper Tremadoc strata within North America.

5.3.2. *Conochitina symmetrica* Zone

This is a total range biozone that characterizes the lowermost Arenig and correlates with the *Tetragraptus approximatus* zone of Europe, North America and Australia (Williams & Stevens, 1991). It is equivalent to the *Conochitina symmetrica* biozone of Northern Gondwana (Paris, 1990, 1996) and Laurentia (Achab, 1989). Although *Conochitina symmetrica* is the index species for the zone, the assemblages from Newfoundland also contain *Conochitina dolosa* (Laufeld, 1967), *Conochitina* sp. cf. *C. elegans* (Eisenack, 1931), *C. minnesotensis* (Stauffer, 1933), *C. simplex* (Eisenack, 1931) and *Rhabdochitina tubularis* (Umnova, 1976). In the Sahara and Bohemia, *C. symmetrica* has been associated with *C. decipiens* and *Lagenochitina esthonica*, with *Eremochitina baculata* forming an

important component of the Saharan biozone. In Quebec, the assemblage is less diverse, but at the base of the Arenig it also contains *C. decipiens*, *C. ventriosa* (Achab, 1980), and *C. pervulgata* (Umnova, 1969).

Conochitina symmetrica is a short ranging, geographically widespread species that is extremely useful as a biostratigraphical marker. In the Sahara, from where it was originally described (Taugourdeau & DeJekhowsky, 1960; Benoit & Taugourdeau, 1961), it has a very limited range which corresponds to the upper part of the "Argiles d'El Gassi" and their equivalents. It characterizes Taugourdeau & DeJekhowsky's (1960) zone 2, or zone D1, of the Saharan oil-company palynologists (Achab, 1989) to which Legrand (1985, p. 27) assigned an early Arenig age. In Australia, Achab & Millepied (1980) identified *C. symmetrica* in cores 5 and 6 (Namheet Formation) of the Samphire Marsh bore-hole of the Canning Basin. In earlier work, Legg (1978) correlated these units (strata) with his Fauna 2, which correspond to the *Paroistodus proteus* conodont Zone and to Zone La3 of the Lancefieldian, considered equivalent to the *T. approximatus* Zone. Paris & Mergl (1984) also described a *Conochitina symmetrica* assemblage from the lowermost part of the Klabava Formation of Bohemia (lowermost *Corymbograptus v. similis* Zone), which is most likely equivalent to Kraft's (1977) *Paratetragraptus approximatus* Zone of Arenigian age.

5.3.3. *Lagenochitina esthonica / Conochitina raymondi* Zone

In Quebec, this zone corresponds to Zone B of the Levis Formation

(Raymond, 1914). It correlates with the old North American *Tetragraptus fruticosus* Zone (Berry, 1960) and the *Didymograptus deflexus* Zone of Great Britain (Barnes *et al.*, 1981), and includes a microfauna consisting of *Lagenochitina esthonica*, *Conochitina raymondi* (Achab, 1980) and *Conochitina ordinaria* (Achab, 1980). In Newfoundland, this zone corresponds with the *Tetragraptus akzharensis* Zone (Williams & Stevens, 1988), and correlates with the top of the *T. approximatus* Zone of North America and the base of the British *Didymograptus deflexus* Zone, approximately equivalent to Paris' (1990, 1996) *Eremochitina baculata* chitinozoan biozone of Northern Gondwana. The chitinozoan species that characterize this zone include a microfauna of *L. esthonica*, C. *raymondi*, *C. minnesotensis*, *C. pervulgata*, *Lagenochitina* sp. cf. *L. baltica* and *L. obeligis*.

Within western Newfoundland, *L. esthonica* makes its first appearance in the middle of the *T. approximatus* Zone (CHN 9.6B/C), however, it doesn't form the useful biostratigraphical association with *C. raymondi* until the base of the *T. akzharensis* Zone (WBN 18A). From this point both species co-occur into the upper Arenig *Isograptus victoriae maximus* Zone, consistent with a similar assemblage from Zone B of the Levis Formation of Quebec (Achab, 1989).

In Bohemia, Paris & Mergl (1984) identified three *L. esthonica* assemblages which range from lower to upper Arenig. The first association is with *C. symmetrica* and *C. decipiens* in the *Corymbograptus v. similis* (Bohemian) Zone of the lowermost part of the Klabava Formation (lower Arenig); this is considered equivalent to the *C. symmetrica* Zone

of Quebec (Achab, 1989) and Northern Gondwana (Paris, 1990, 1996). The second association, within the middle part of the *Schizograptus tardibrachiatus* (Bohemian) Zone of early-middle Arenig age (Jackson, 1962; Kraft, 1977; Kraft & Mergl, 1979), lies above the *Conochitina symmetrica* assemblage in association with *Tanuchitina achabae* (Paris, 1981) and *C. decipiens*. The third and youngest assemblage of *L. esthonica* and *C. decipiens* was recovered from the upper part of the Klabava Formation (upper Arenig) within the middle part of the *Tetragraptus* cf. *pseudobigsbyi* Zone, which is equivalent to the *Didymograptus hirundo* Zone of Great Britain.

The range of occurrence of *L. esthonica* within this study correlates well with other North American (Achab, 1986a, 1989), European (Bockelie, 1980; Grahn, 1980; Paris, 1981) and north African (Paris & Mergl, 1984) sections. The more elongated forms described by Bockelie (1980), Grahn (1980), Paris (1981) and Paris & Mergl (1984) may not be conspecific with true *L. esthonica*; rather, they closely resemble forms I attributed to *L. maxima*. The species' [*L. esthonica*] co-occurrence with other well-established Arenig taxa (e.g. *C. decipiens*) provides a critical marker for evaluating Lower Ordovician sections.

In the Sahara, Benoit & Taugourdeau (1961) identified a rare fauna of *L. esthonica* in association with *Eremochitina baculata* and *Velatachitina pellucida* (Taugourdeau & DeJekhowsky, 1960). Located between the *Didymograptus extensus* Zone and an assemblage containing *Conochitina symmetrica*, this fauna presumably lies at the top of the *Tetragraptus approximatus* Zone. Until now (assuming present examples of *Eremochitina* sp. cf. *E.*

baculata are actually conspecific with true *Eremochitina baculata*), *Eremochitina baculata* has not been reported in the Lower Ordovician of eastern North America, but rather forms an important element of middle Arenigian chitinozoan assemblages (*D. extensus* Zone) of the Sahara (Taugourdeau & DeJekhowsky, 1960; Benoit & Taugourdeau, 1961; Taugourdeau, 1967), southwestern Europe (Paris, 1981), and Morocco (Elaouad-Debbaj, 1984).

5.3.4. *Conochitina langei / Conochitina brevis* Zone

Achab (1989) used this assemblage to define the base of Zone C (*D. protobifidus* Zone to the top of the *I. v. victoriae* Zone) of the Levis Formation, which was originally described from a *Didymograptus* fauna and equivalent to the base of the *Didymograptus nitidus* Zone of Great Britain. In western Newfoundland, the *Conochitina langei / Conochitina brevis* Zone appears at the base of the *Didymograptus bifidus* zone and corresponds with the *Desmochitina ornensis* biozone of Northern Gondwana (Paris, 1990). The *C. langei / C. brevis* Zone is a long-ranging zone that extends to the base of the *Isograptus victoriae maximus* Zone of North American (western Newfoundland) and the *Didymograptus hirundo* Zone of Great Britain. The microfauna of western Newfoundland contained frequent examples of *Conochitina brevis* in association with the marker species *C. langei*. The abundance and unambiguous, easily recognizable silhouettes of both *C. langei* (club-shaped; pl. 1, figs. 26-36) and *C. brevis* (purse-shaped; pl. 1, figs. 1-5) makes these two

taxa extremely useful in defining middle to early-upper Arenig graptolite zones, strengthening an affinity between Arenigian assemblages of Quebec and western Newfoundland.

5.3.5. **Cyathochitina dispar* Zone

This narrow zone corresponds in part with the base of Achab's (1989) *Belonechitina pirum* zone and overlaps a hiatus zone directly below the *Desmochitina bulla* zone of Northern Gondwana (Paris, 1990, 1996). It is used "loosely" to define the base of the *Isograptus victoriae maximus* graptolite zone of western Newfoundland (Williams & Stevens, 1988).

Cyathochitina dispar (Benoit & Taugourdeau, 1961) is a relatively simple chitinozoan, with a stout form and very narrow (or short) carina that easily separates it from other cyathochitinids (pl. 4, figs. 1-3). This species has been recovered from Arenigian (Benoit & Taugourdeau, 1961; Martin, 1969) and lower Llanvirnian (Martin, 1969; McClure, 1988) strata of Europe and Africa. Taugourdeau (1961) identified a subspecies of *C. dispar*, "*verrucata*" from the lower Silurian of Aquitaine which he later (Taugourdeau, 1965) reported from the Upper Ordovician (Caradoc?) of Oklahoma. It differs from *C. dispar* in having wart-like verrucae covering its outer wall and a carina that curves inward from the basal margin and below the base. If the morphological and stratigraphical separation of parent and subspecies is justified, then both taxa may be of biostratigraphical value in

recognizing both Lower and Upper Ordovician strata. At present, *C. dispar* is used as a marker for this zone in the absence of other stratigraphically useful and well-established taxa.

5.3.6. ***Laufeldochitina* sp. Zone**

The *Laufeldochitina* sp. Zone defines the uppermost Arenig within the Cow Head Group. It corresponds with Williams & Stevens' (1988) *Undulograptus austrodentatus* Zone and the uppermost *Isograptus* and *Didymograptus hurundo* zones of North America (Berry, 1960; Finney, 1982) and Great Britain (see Williams & Stevens, 1988 for further references), respectively. It is equivalent to the very top of the *Belonechitina pirum* biozone of Quebec (Achab, 1989) and the *Desmochitina bulla* biozone of Northern Gondwana (Paris, 1990, 1996). Although *Laufeldochitina* sp. (Paris, 1981) has not been previously documented from other Laurentian strata of late Arenig age, its unambiguous morphological characteristics (e.g. elongated trumpet shape) suggests it may be a useful tool in correlating similar North American, European and Baltic strata.

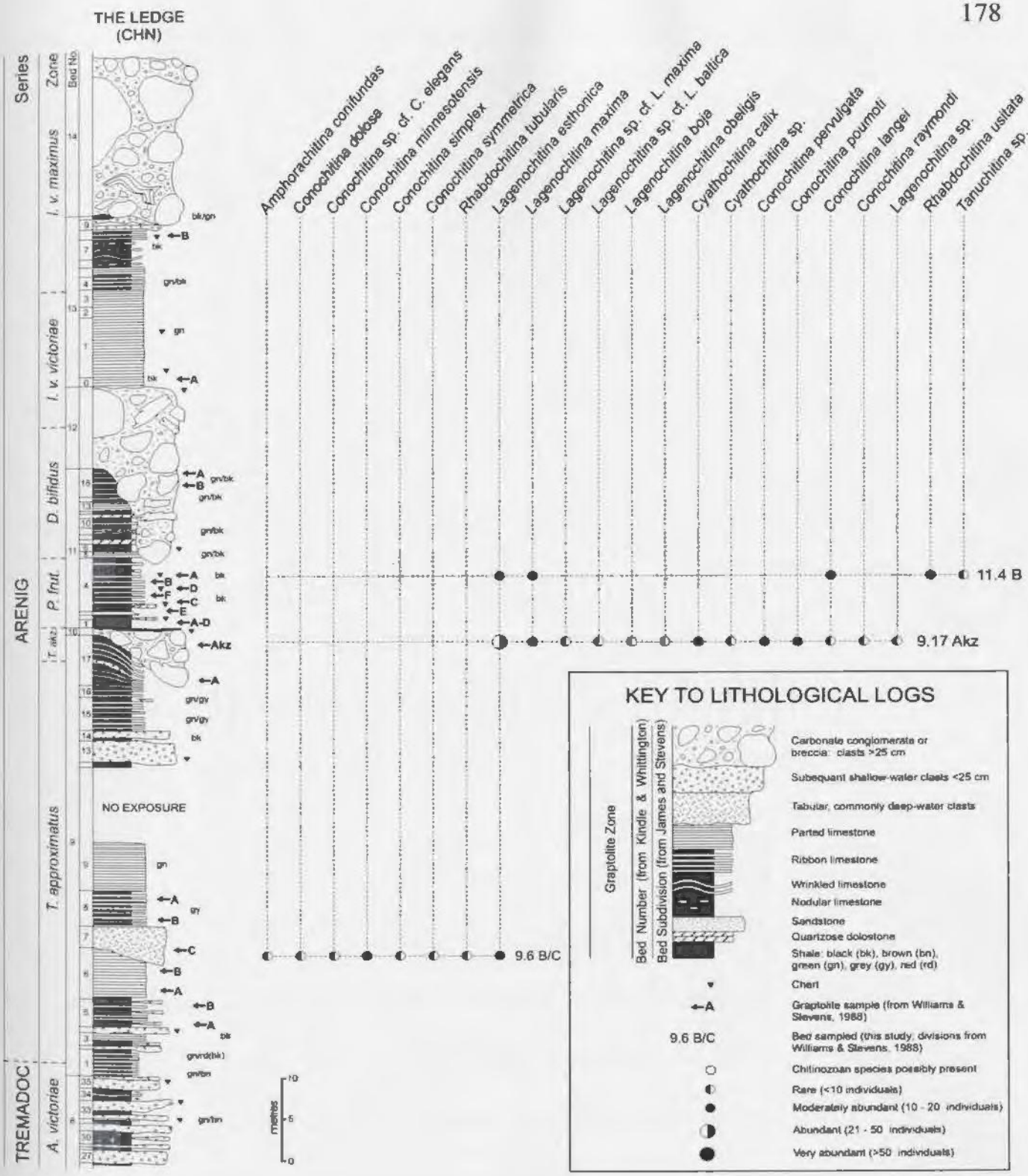
5.4 Supplementary Note

Achab (1983) described a microfaunal assemblage from the middle part of the Table Head Formation of western Newfoundland consisting of *Conochitina turgida*, *Conochitina subcylindrica*, *Spinachitina* cf. *S. bulmani* (Jansonius, 1964), *Desmochitina lata* (Schallreuter, 1963), *Belonechitina pirum*, *C. langei* and *C. poumoti*, which defined the base

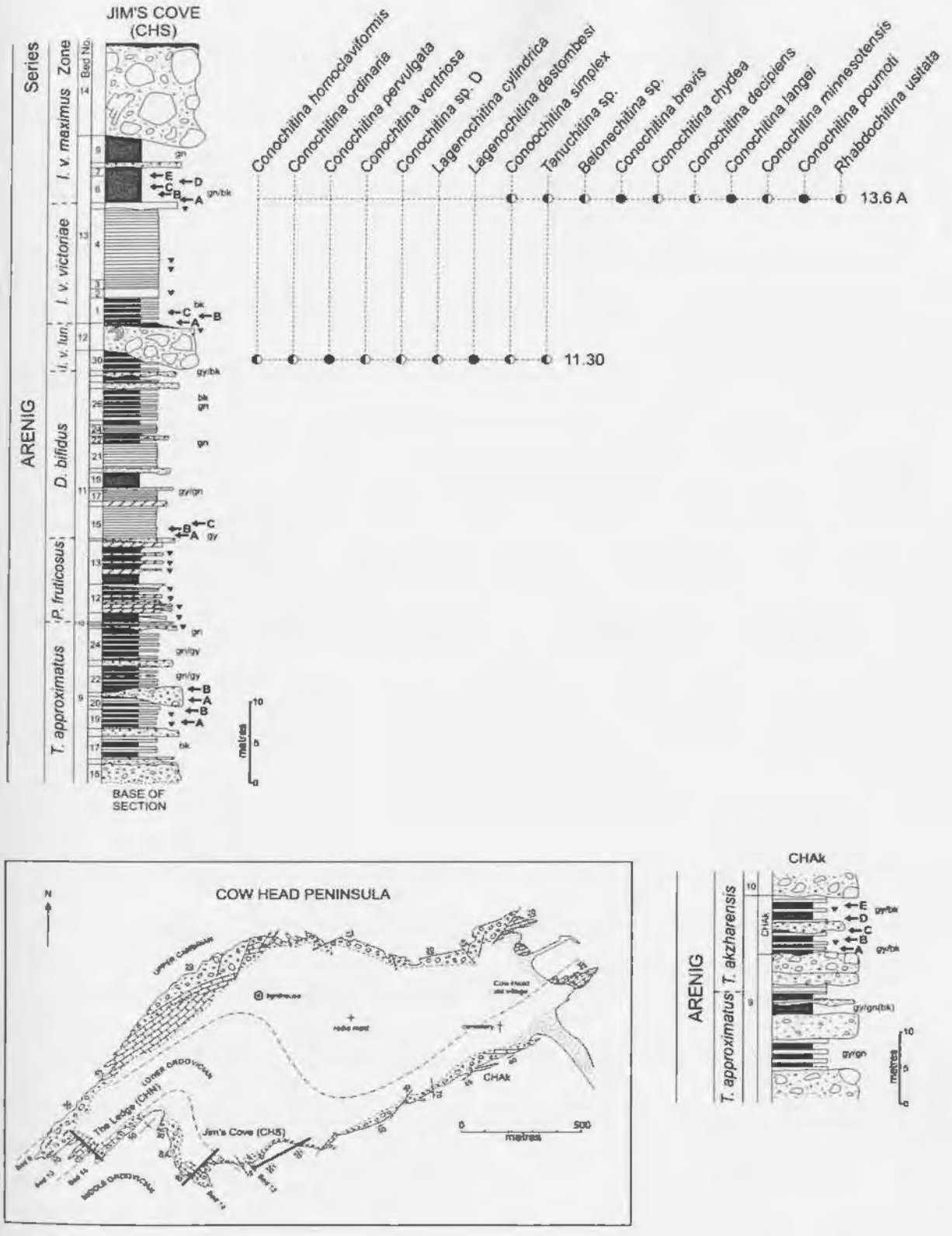
of the Llanvirn using the old North American graptolite zone *Didymograptus decoratus*, and corresponds with the *Didymograptus artus* graptolite zone of Great Britain and the *Cyathochitina protocalix* and *CyathocHitina calix* chitinozoan biozones of Northern Gondwana (Paris, 1990, 1996).Years earlier, Martin (1978) identified a similar fauna from the middle part of the Table Head Formation (middle Llanvirn) of western Newfoundland.

Within the Cow Head Group, an assemblage of *C. turgida* and *C. subcylindrica*, commonly associated with *C. brevis*, *C. poumoti* and *C. langei*, was identified at the base of the *Didymograptus bifidus* (Newfoundland) and middle of the *Didymograptus nitidus* (Great Britain) graptolite zones, which overlap Achab's (1989) *C. langei / C. brevis* chitinozoan biozone and correspond with the base of Paris' (1990, 1996) *Desmochitina ornensis* chitinozoan biozone of Northern Gondwana.

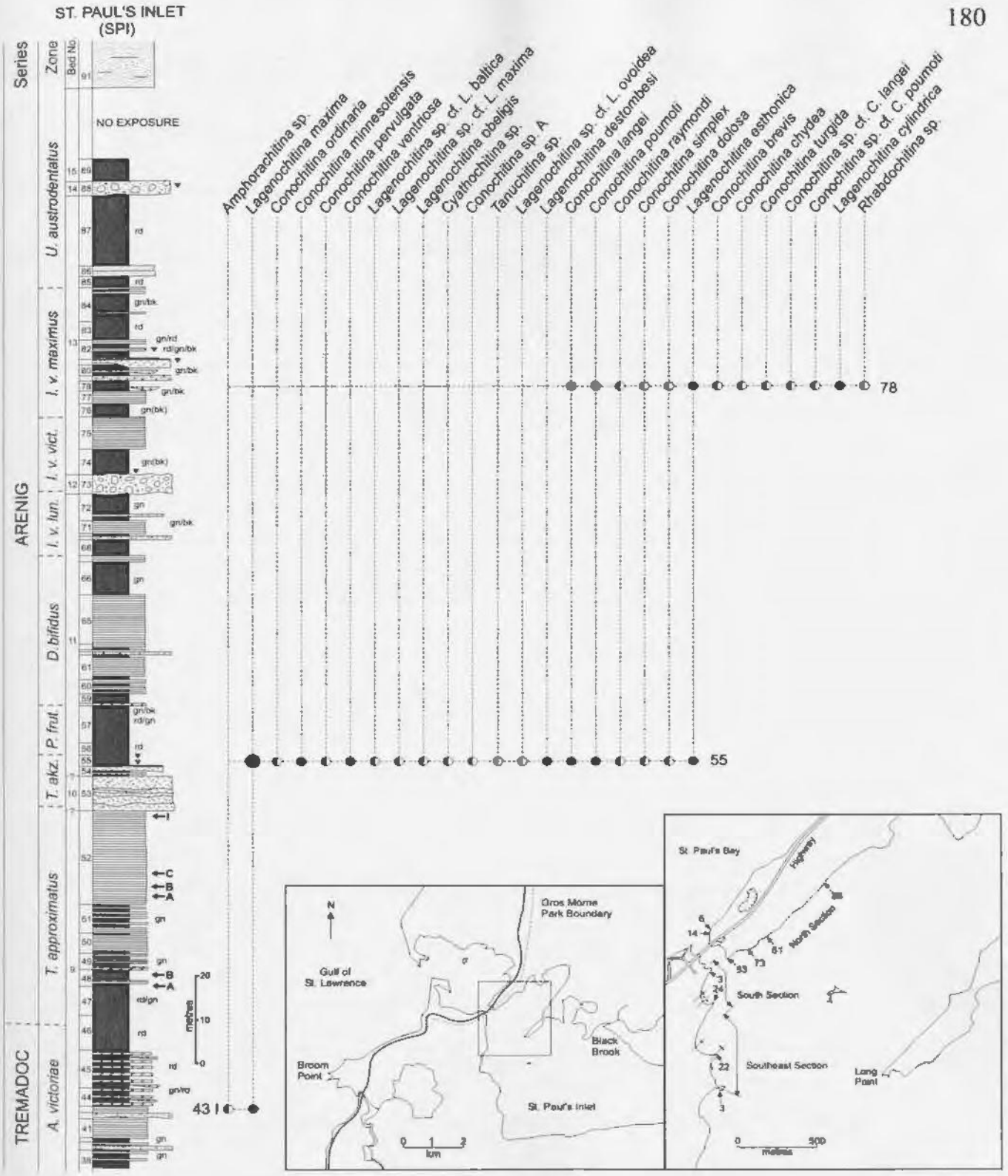
The presence of *C. turgida* and *C. subcylindrica* within the present study represents the earliest occurrence of either of these taxa within North America (Jenkins, 1969, 1970a; Neville 1974; Martin, 1978; Achab 1983, 1989), Europe (Jenkins, 1967) or Australia (Combaz & Péniguel, 1972). Unfortunately, this weakens their stratigraphical reliability for dating basal Llanvirnian strata; a further refining of Achab's (1989) Laurentian biozones is warranted. Although *Belonechitina pirum* has not been positively identified within the Newfoundland assemblage, its presence would at least strengthen the affinity between similar assemblages of eastern Canada (Quebec and western Newfoundland) and Australia. Its absence in the upper Arenig from other than North American strata suggests that this species likely has limited biostratigraphical application.



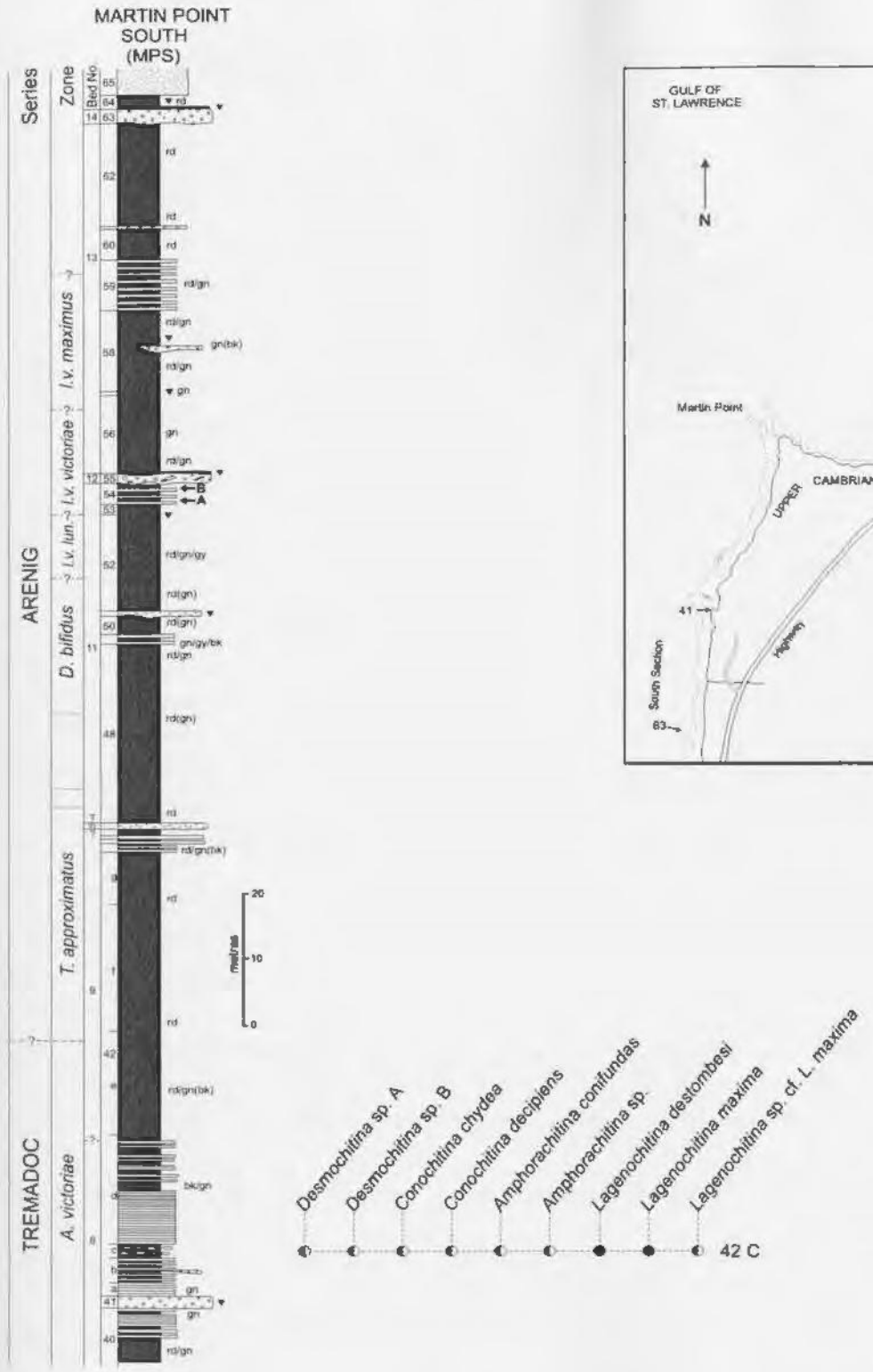
Text-Figure 5.1. Lithological log of the Ledge section, Cow Head Peninsula showing chitinozoan occurrences and relative abundances. Inset is key to this log and all subsequent logs (redrawn from Williams & Stevens, 1988; after James & Stevens, 1986).



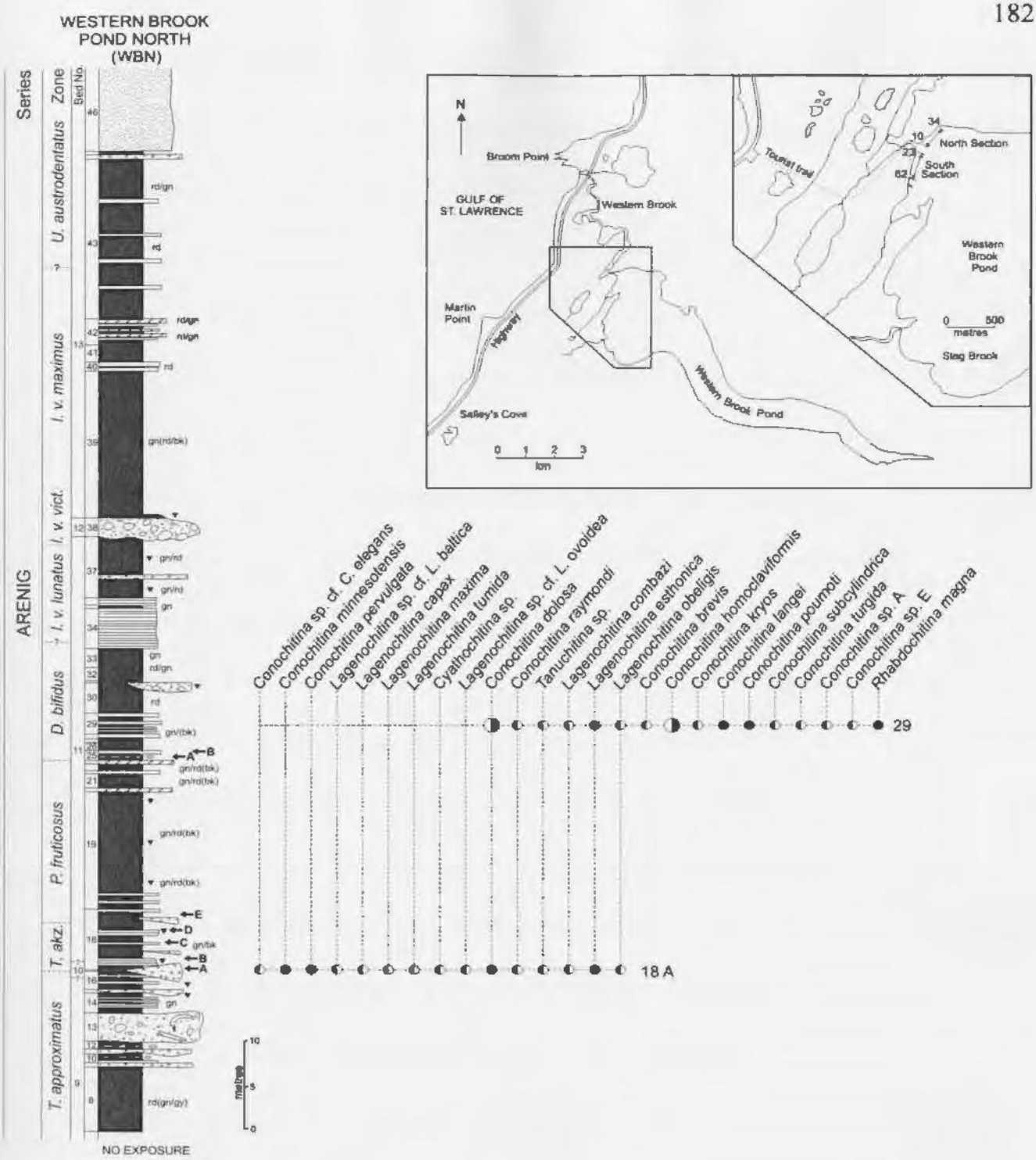
Text-Figure 5.2. Lithological of the Jim's Cove section, Cow Head Peninsula showing chitinozoan occurrences and relative abundances (redrawn from Williams & Stevens, 1988; after James & Stevens,1986).



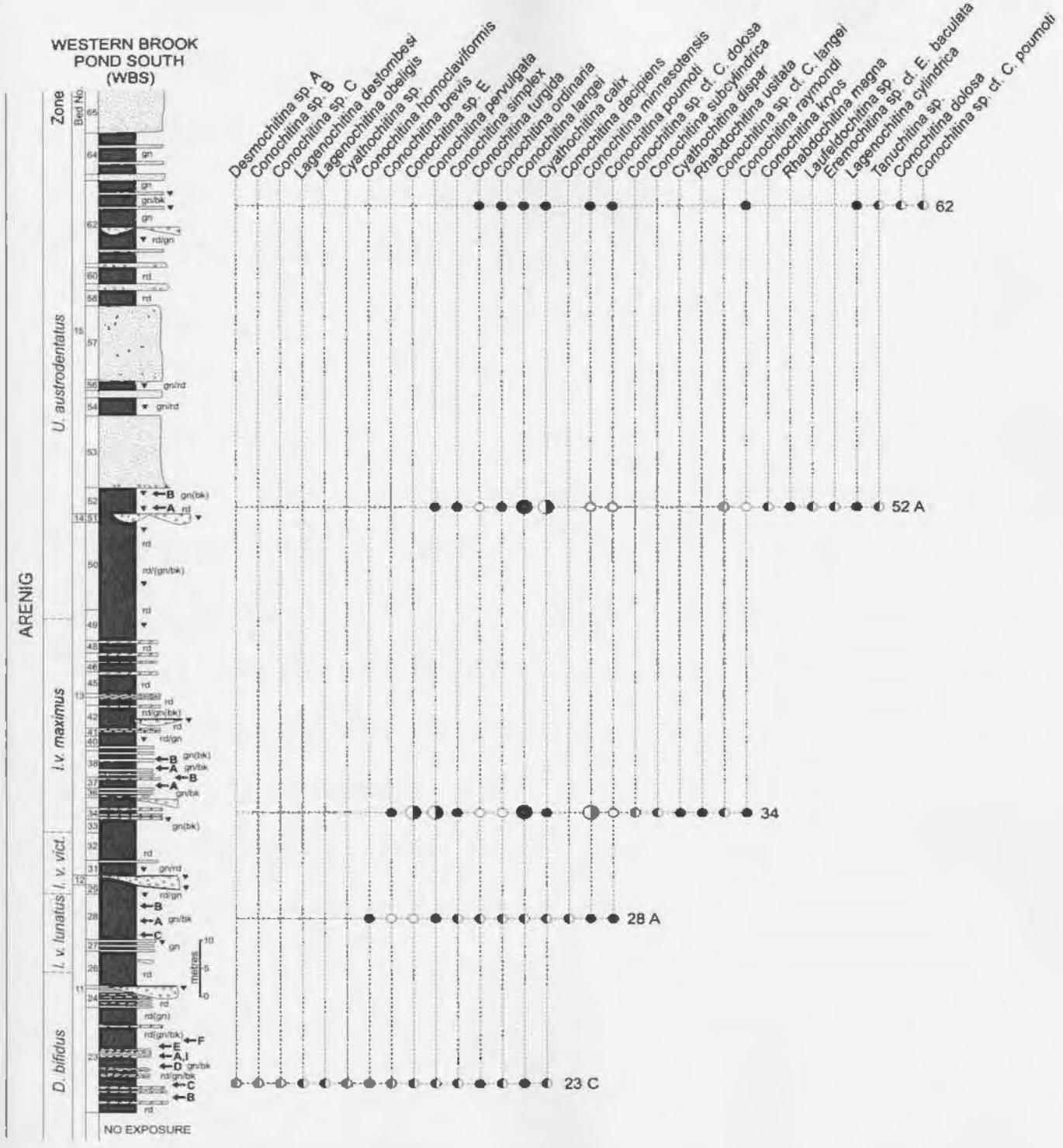
Text-Figure 5.3. Lithological log of the St. Paul's Inlet, North Tickle section showing chitinozoan occurrences and relative abundances (redrawn from Williams & Stevens, 1988; after James & Stevens, 1986).



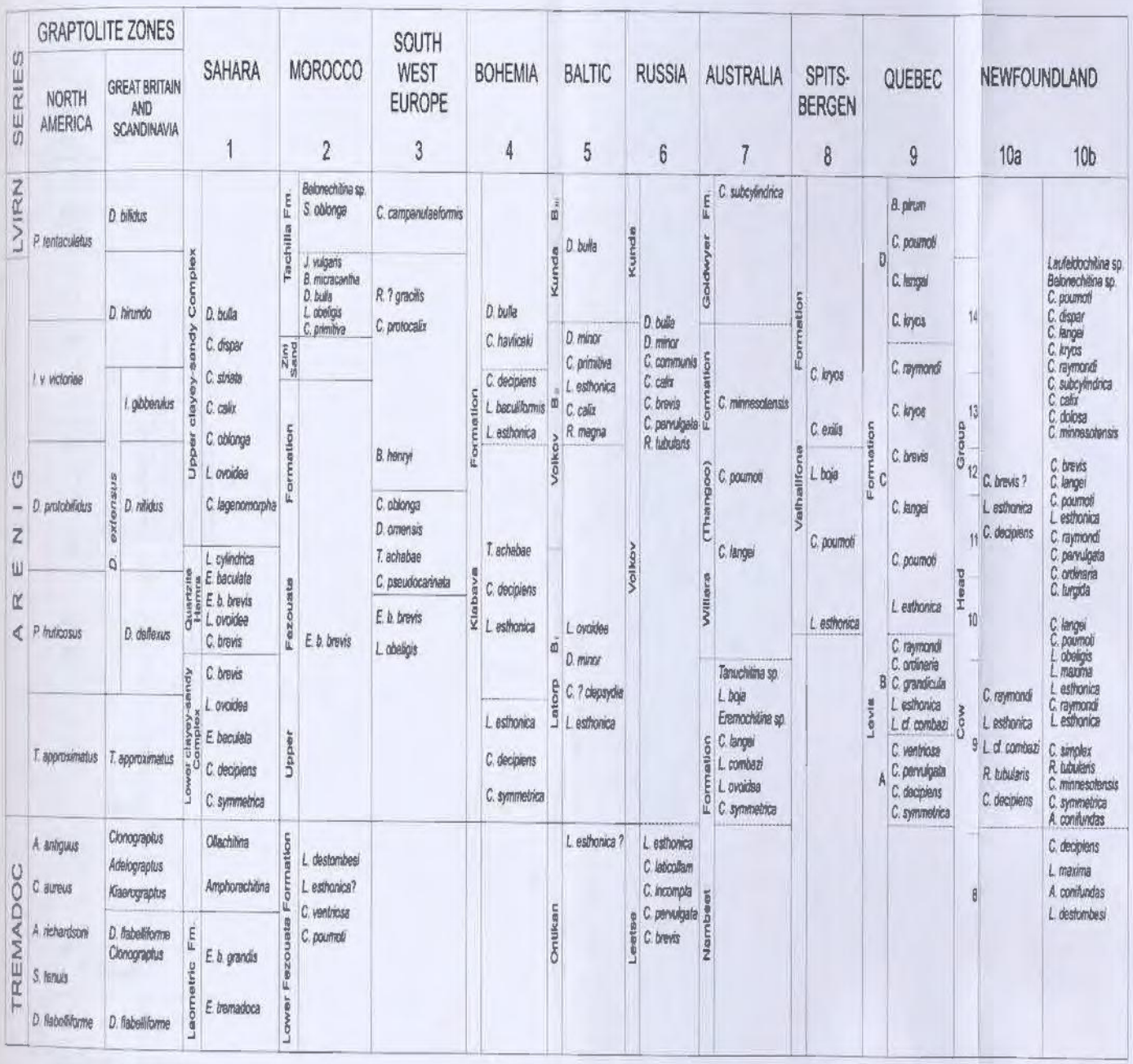
Text-Figure 5.4. Lithological log of the Martin Point South section showing chitinozoan occurrences and relative abundances (redrawn from Williams & Stevens, 1988; after James & Stevens, 1986).



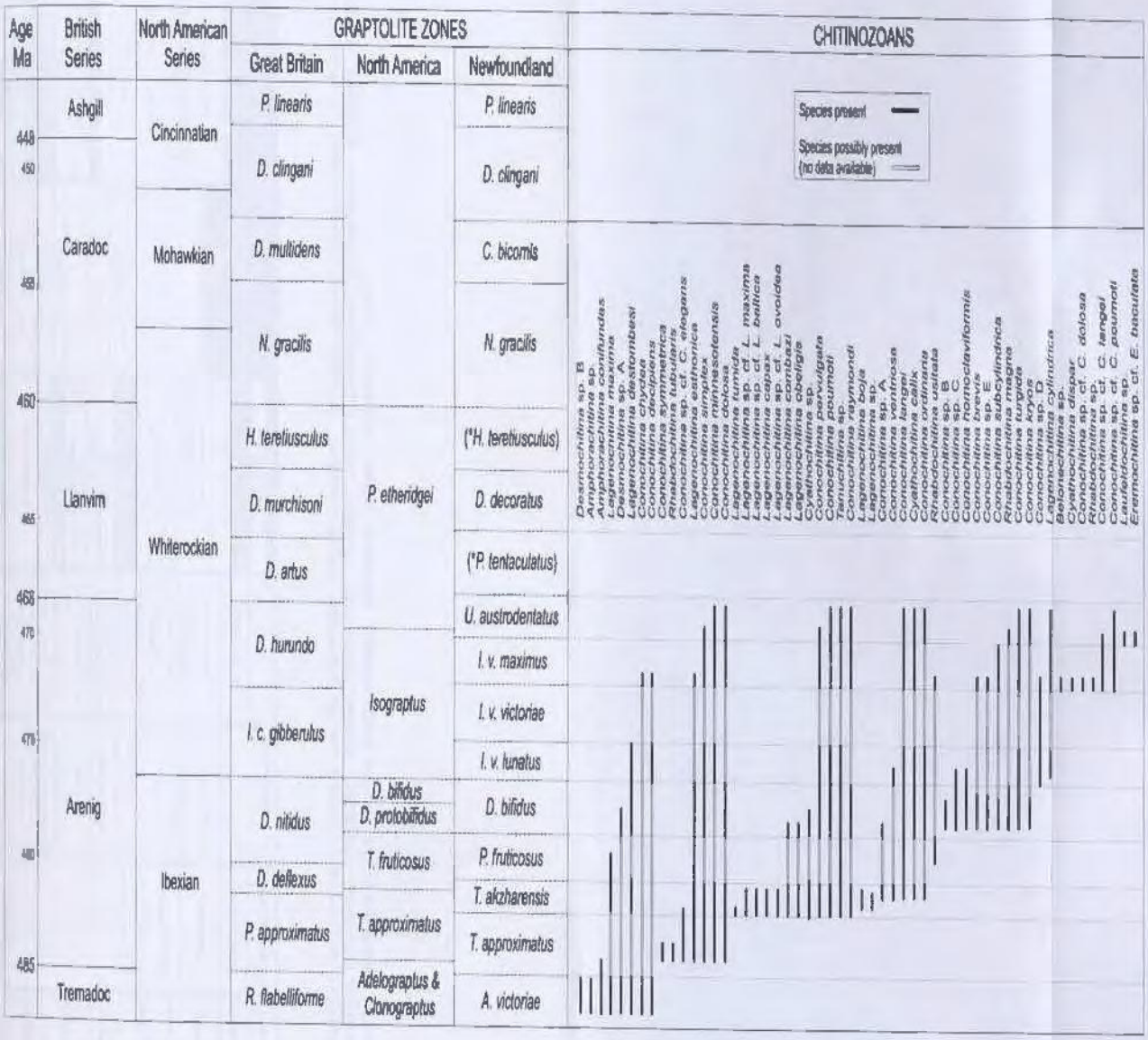
Text-Figure 5.5. Lithological log of the Western Brook Pond North section showing chitinozoan occurrences and relative abundances (redrawn from Williams & Stevens, 1988; after James & Stevens, 1986).



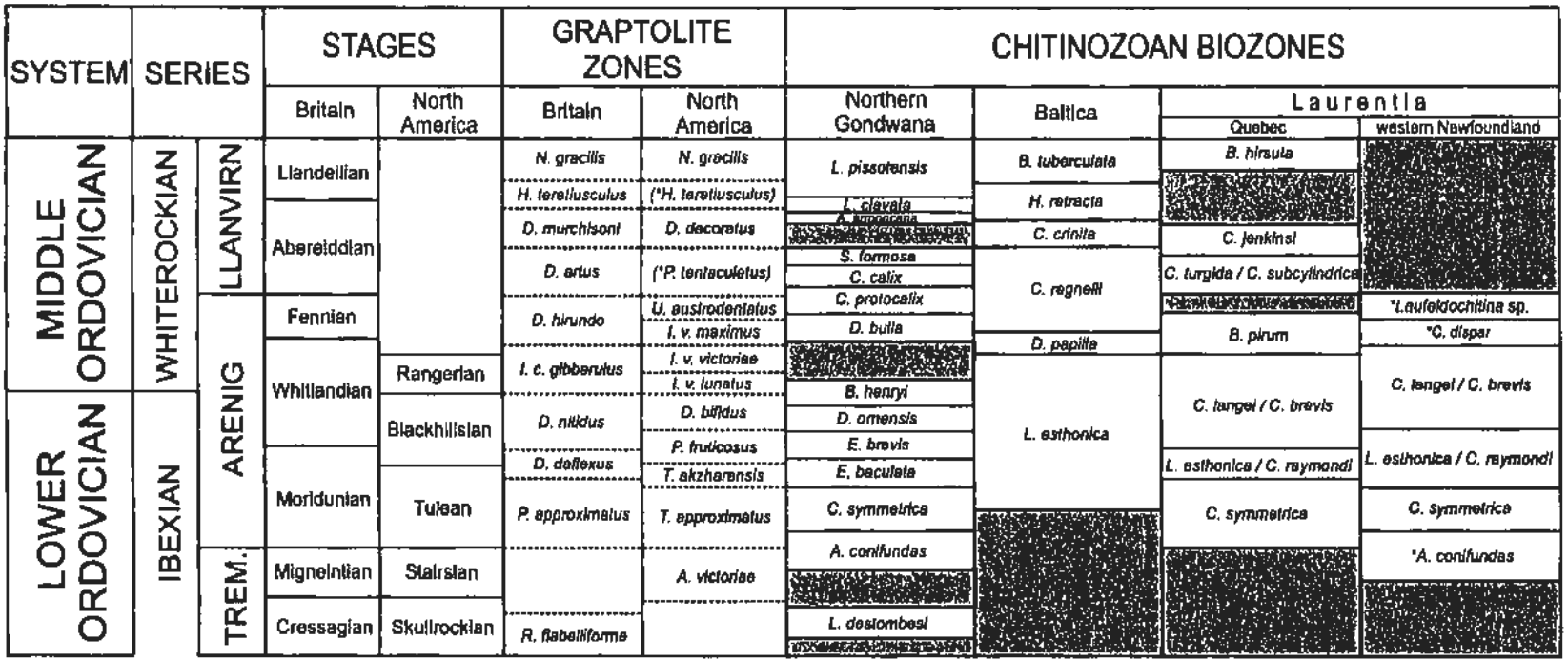
Text-Figure 5.6. Lithological log of the Western Brook Pond South section showing chitinozoan occurrences and relative abundances (redrawn from Williams & Stevens, 1988; after James & Stevens, 1986).



Text-Figure 5.7. Summary of important Lower Ordovician chitinozoans assemblages (1. Benoit & Taugourdeau, 1961; 2. Elaouad-Debbaj, 1984, 1988; 3. Paris, 1981; 4. Paris & Mergl, 1984; 5. Eisenack, 1958, 1968; 6. Umnova, 1969; 7. Combaz & Péniguel, 1972; Achab & Millepied, 1980; 8. Bockelie, 1980; 9. Achab, 1980, 1982; 10a. Achab, 1986a; 10b. This study; Redrawn from Achab,1986a).



Text-Figure 5.8. Summary range chart of Lower Ordovician chitinozoans from the Cow Head Group, western Newfoundland (graptolite zones from Williams & Stevens, 1988; Series after Webby, 1998).



Text-Figure 5.9. Correlation chart of Lower and Middle Ordovician chitinozoan biozones of Northern Gondwana (Paris, 1990, 1996), Baltica (Grahn, 1982c, 1984; Nõlvak, 1990), and Laurentia (Quebec: Achab, 1989; and western Newfoundland: this study). British and North American Stages after Webby, 1998.

CONCLUSIONS

1) Systematic analysis of Lower Ordovician [Arenigian] sections within the Cow Head Group, central western Newfoundland yielded abundant and well-preserved chitinozoans from which a total of 32 named species, and 22 taxa of uncertain specific position representing 9 genera were identified and described. Two taxa (*Amphorachitina conifundas*, *Lagenochitina destombesi*) were not previously recorded from the Lower Ordovician of eastern Canada.

2) The persistence of chitinozoans within strata of the Cow Head Group that also yielded abundant and diverse graptolite assemblages suggests that these microfossil groups may share a biological affinity or have similar environmental preferences.

3) Preliminary evidence suggests the chitinozoans of western Newfoundland were not distributed randomly across the Lower Ordovician Cow Head Group slope deposit, but rather were under the influence of complex environmental and ecological influences, possibly reflecting their planktonic or benthic lifestyles, or were distributed under control of intricate sedimentological processes.

4) While much of the processed material from the Cow Head Group consisted of "clean" black shales and thinly bedded limestones which yielded well-preserved and easily identifiable chitinozoans, several samples [from St. Pauls Inlet and Western Brook Pond]

were heavily mineralized and of generally poor quality.

5) The co-occurrence of biostratigraphically useful taxa, *Amphorachitina conifundas*, *Lagenochitina esthonica*, *Lagenochitina destombesi*, *Conochitina symmetrica*, *Conochitina langei*, *Conochitina brevis* and *Cyathochitina dispar* within upper Tremadoc and Arenig sections of the Cow Head Group form species associations that were used to define 6 biozones (*Amphorachitina conifundas*, *Conochitina symmetrica*, *Lagenochitina esthonica / Conochitina raymondi*, *Conochitina langei / Conochitina brevis*, *Cyathochitina dispar*, *Laufeldochitina* sp.) through the Lower Ordovician. These zones correlate well with similar sections from Quebec and Australia, and establish close relationships with other Laurentian sections in North America and with the Gondwanan domains of Europe, the Baltic and north Africa.

6) This study is only one of a select few so far carried out on the chitinozoa of western Newfoundland, and likely is the most comprehensive to date. It is the hope of the author that this research will contribute to ever growing knowledge on this enigmatic group, and form the framework on which future chitinozoan studies within western Newfoundland will be based.

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APPENDIX I - PLATES

PLATE 1

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-5. *Conochitina brevis* Taugourdeau & DeJekhowsky 1960.
1. WBN29-09, *D. bifidus* Zone.
2. SPI78-05, *I. v. maximus* Zone.
3, 5. WBS34-02, 04, *I. v. maximus* Zone.
4. Slightly elongated specimen, CHS13.6A-06, *I. v. maximus* Zone.

Figs. 6-8. *Conochitina chydea* Jenkins 1967, CHS13.6A-07, 12, 13, *I. v. maximus* Zone.

Figs. 9-12. *Conochitina decipiens* Taugourdeau & DeJekhowsky 1960.
9. WBS28A-09, *I. v. lunatus* Zone.
10. CHS13.6A-09, *I. v. maximus* Zone.
11. CHN9.17AKZ-13, *T. akzharensis* Zone.
12. MPS42C- 03, *A. victoriae* Zone.

Fig. 13. *Conochitina* sp. cf. *C. elegans* Eisenack 1931, CHN9.6BC-03, *T. approximatus* Zone.

Figs. 14-17. *Conochitina dolosa* Laufeld 1967.
14, 16. SPI55-13, 11, *T. akzharensis* Zone.
15, 17. WBN29-17, 04, *D. bifidus* Zone.

Figs. 18-23. *Conochitina homoclaviformis* Taugourdeau 1961.
18, 21. WBN29-03, 01, *D. bifidus* Zone.
21. Specimen compressed longitudinally with concave base.
19, 20, 23. WBS28A-04, 03, 07, *I. v. lunatus* Zone.
22. WBS23C-08, *D. bifidus* Zone.

Figs. 24, 25. *Conochitina kryos* Bockelie 1980.
24. WBS52A-13, *U. austrodentatus* Zone.
25. Specimen with flattened base, WBN29-14, *D. bifidus* Zone.

Fig. 26. *Conochitina* sp. cf. *C. dolosa* Laufeld 1967, WBS34-06, *I. v. maximus* Zone.

Fig. 27-37. *Conochitina langei* Combaz & Péniguel 1972.
27, 35. WBS23C-11, 02, *D. bifidus* Zone.
28, 31, 32, 34. CHS13.6A-03, 10, 04, 09, *I. v. maximus* Zone.
29, 33, 36. WBS34-24, 25, 07, *I. v. maximus* Zone.
30. CHN9.17AKZ-15, *T. akzharensis* Zone.
37. WBS52A-04, *U. austrodentatus* Zone.

PLATE 1

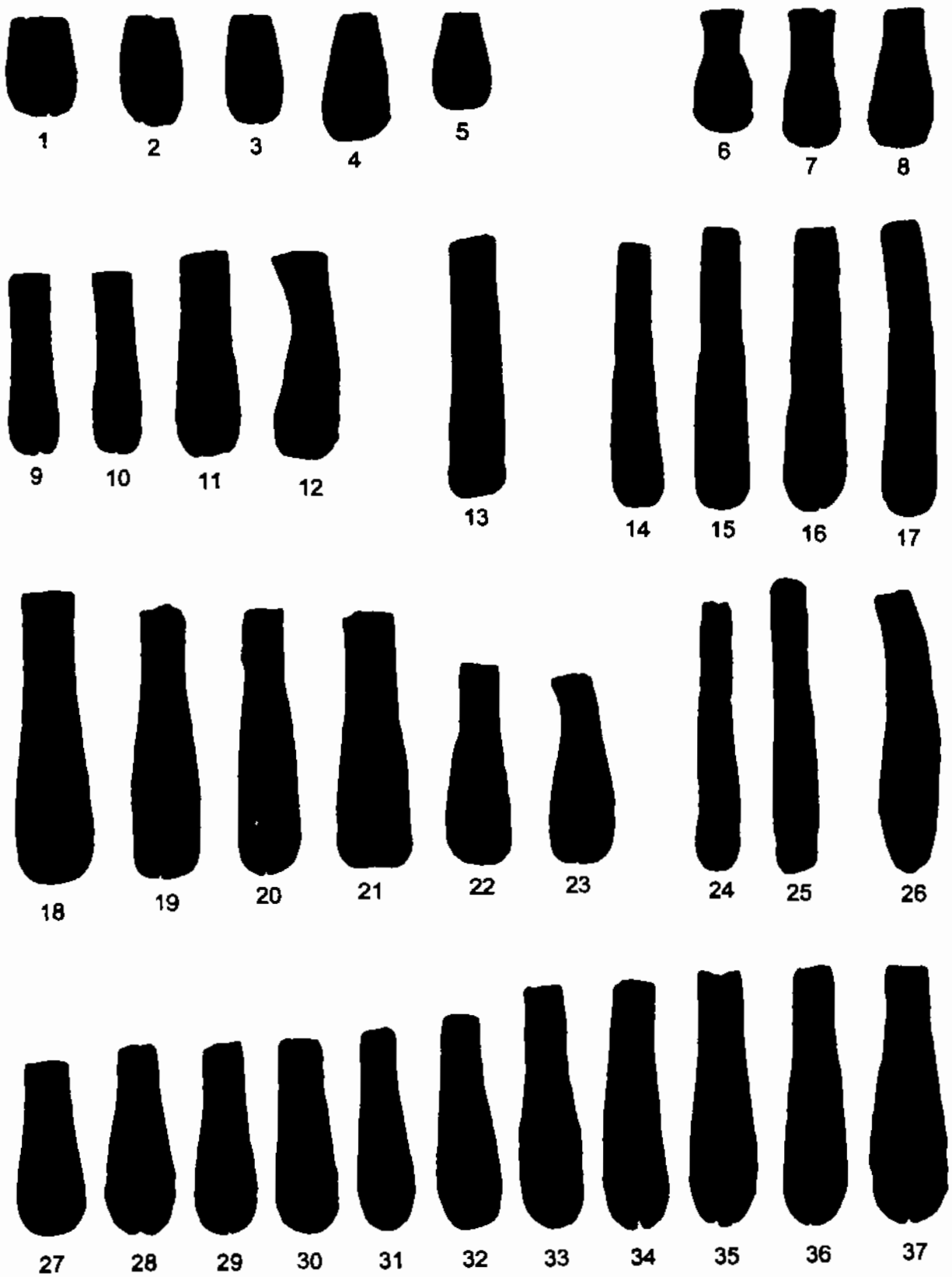
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PLATE 2

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-8. *Conochitina minnesotensis* Stauffer 1933; 4, vesicle with fractured base; 8, lateral expansion of the shoulders.

1, 8. CHN9.6BC-01, 08, *T. approximatus* Zone; 8, lateral expansion of vesicle.
2. Specimen with fractured aperture, WBS62-02, *U. austrodentatus* Zone.
3. Base with mucron, WBS34-01, *I. v. maximus* Zone.
4-6. SPI55-17, 12, 14, *T. akzharensis* Zone; 4, fractured base.
7. WBS28A-01, *I. v. lunatus* Zone.

Fig. 9. *Rhabdochitina magna* Eisenack 1931, WBN29-11, *D. bifidus* Zone.

Fig. 10. *Rhabdochitina* sp., SPI78-01, *I. v. maximus* Zone.

Figs. 11, 12. *Conochitina symmetrica* Taugourdeau & DeJekhowsky 1960, CHN9.6BC-07, 08, *T. approximatus* Zone.

Figs. 13-15. *Conochitina ordinaria* Achab 1980, WBS28A-12, 11, 10. *I. v. lunatus* Zone; 13, vesicle with fractured base.

Figs. 16-22. *Conochitina poumoti* Combaz & Péniguel 1972.

16. WBS62-03, *U. austrodentatus* Zone.
17, 20. SPI78-03, 02, *I. v. maximus* Zone.
18, 22. CHN9.17AKZ-14, 16, *T. akzharensis* Zone.
19, 21. CHS13.6A-02, 08, *I. v. maximus* Zone.

Figs. 23-25. *Conochitina* sp. cf. *C. poumoti* Combaz & Péniguel 1972, WBS62-10, 08, 09, *U. austrodentatus* Zone.

Figs. 26-31. *Conochitina pervulgata* Umnova 1969.

26, 29. WBS28A-08, 02, *I. v. lunatus* Zone.
27, 28. WBS52A-07, 06, *U. austrodentatus* Zone; 28, specimen with flattened base.
30. CHS11.30-09, *I. v. lunatus* Zone.
31. CHN9.17AKZ-15, *T. akzharensis* Zone.

Fig. 32. *Conochitina subcylindrica* Combaz & Péniguel 1972, WBS34-17, *I. v. maximus* Zone.

Figs. 33-35. *Conochitina simplex* Eisenack 1931.

33. CHN9.6BC-06, *T. approximatus* Zone.
35, 35. CHS11.30-05, 07, *I. v. lunatus* Zone.

Figs. 36-41. *Conochitina turgida* Jenkins 1967.

36, 39. WBS23C-12, 11, *D. bifidus* Zone; 36, compressed specimen with fractured base.
37. WBS28A-14, *I. v. lunatus* Zone.
38. SPI78-10, *I. v. maximus* Zone.
40, 41. WBS62-05, 06, *U. austrodentatus* Zone.

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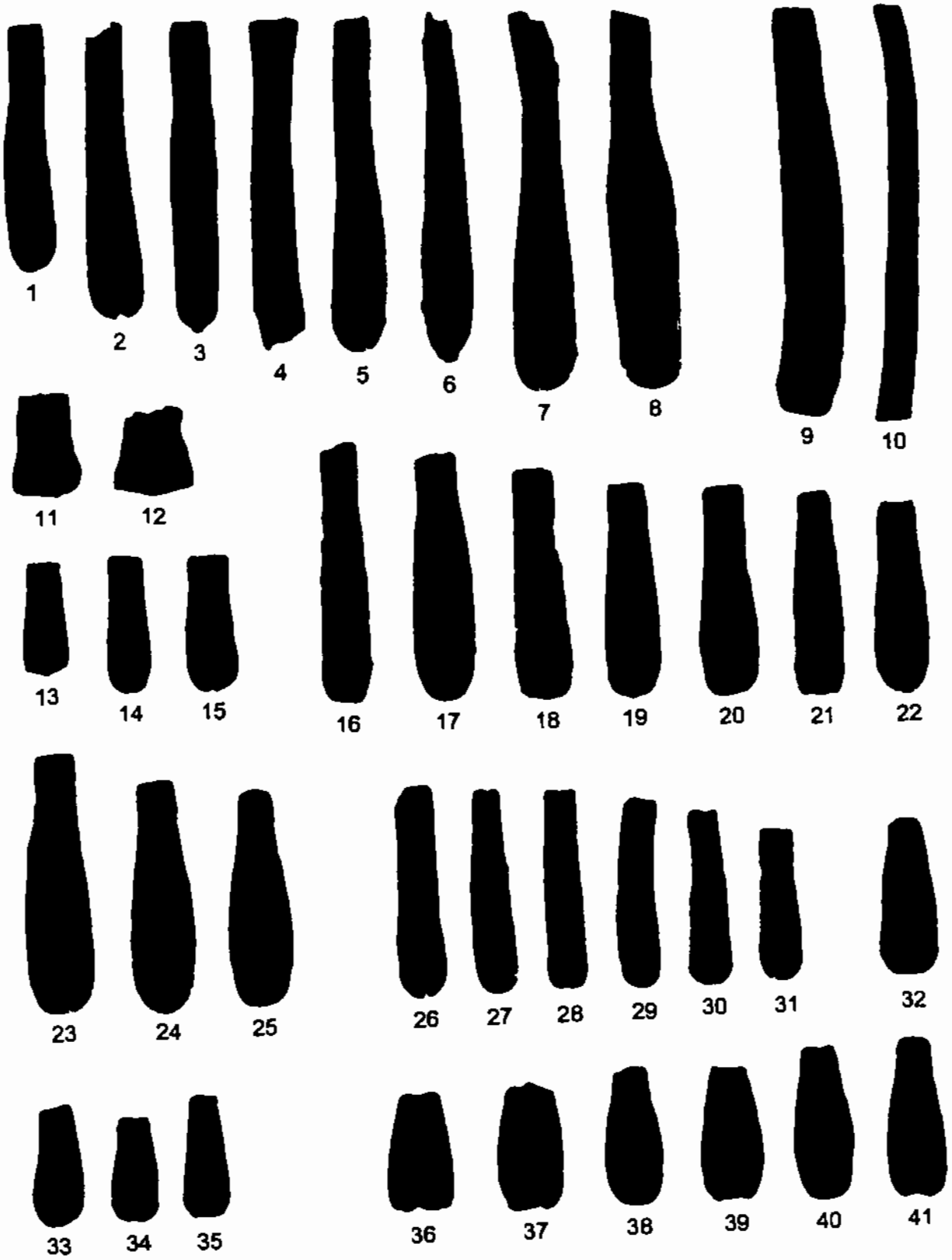
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PLATE 3

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-5. *Conochitina raymondi* Achab 1980.
1. WBN29-18, *D. bifidus* Zone.
2, 5. SPI78-07, 06, *I. v. maximus* Zone.
3. WBS34-05, *I. v. maximus* Zone.
4. WBS62-03, *U. austrodentatus* Zone.

Figs. 6, 7. *Conochitina ventriosa* Achab 1980, SPI55-15, 14, *T. akzharensis* Zone; 6, chamber stretched longitudinally.

Fig. 8. *Conochitina* sp. A, WBN29-12, *D. bifidus* Zone.

Fig. 9. *Conochitina* sp. B, WBS23C-09, *D. bifidus* Zone.

Figs. 10-12, 21. *Conochitina* sp. C; 10, 12, CHS11.30-02, 01, *I. v. lunatus* Zone; 11, 21, WBN29-13, 19 *D. bifidus* Zone.

Figs. 13-15. *Conochitina* sp. D; 13, 14, WBS23C-07, 05, *D. bifidus* Zone; 15, WBS34-13, *I. v. maximus* Zone.

Figs. 16, 17. *Conochitina* sp. E; 16, WBS34-03, *I. v. maximus* Zone; 17, WBN29-05, *D. bifidus* Zone.

Fig. 18. *Desmochitina* sp. A, MPS42C-13, *A. victoriae* Zone.

Fig. 19. *Desmochitina* sp. B, elongated and distorted chain, MPS42C-13, *A. victoriae* Zone.

Fig. 20. *Eremochitina* sp. cf. *E. baculata* Taugourdeau & DeJekhowsky 1960, note large basal mucron, WBS52A-11, *U. austrodentatus* Zone.

Figs. 22, 23. *Laufeldochitina* sp., WBS52A-10, 09, *U. austrodentatus* Zone.

Fig. 24. *Belonechitina* sp., CHS13.6A-01, *I. v. maximus* Zone.

Figs. 25-29. *Conochitina* sp. cf. *C. langei* Combaz & Péniguel 1972.
25. SPI78-12, *I. v. maximus* Zone.
26, 27, 29. WBS34-11, 16, 15, *I. v. maximus* Zone.
28. WBS52A-05, *U. austrodentatus* Zone.

PLATE 3

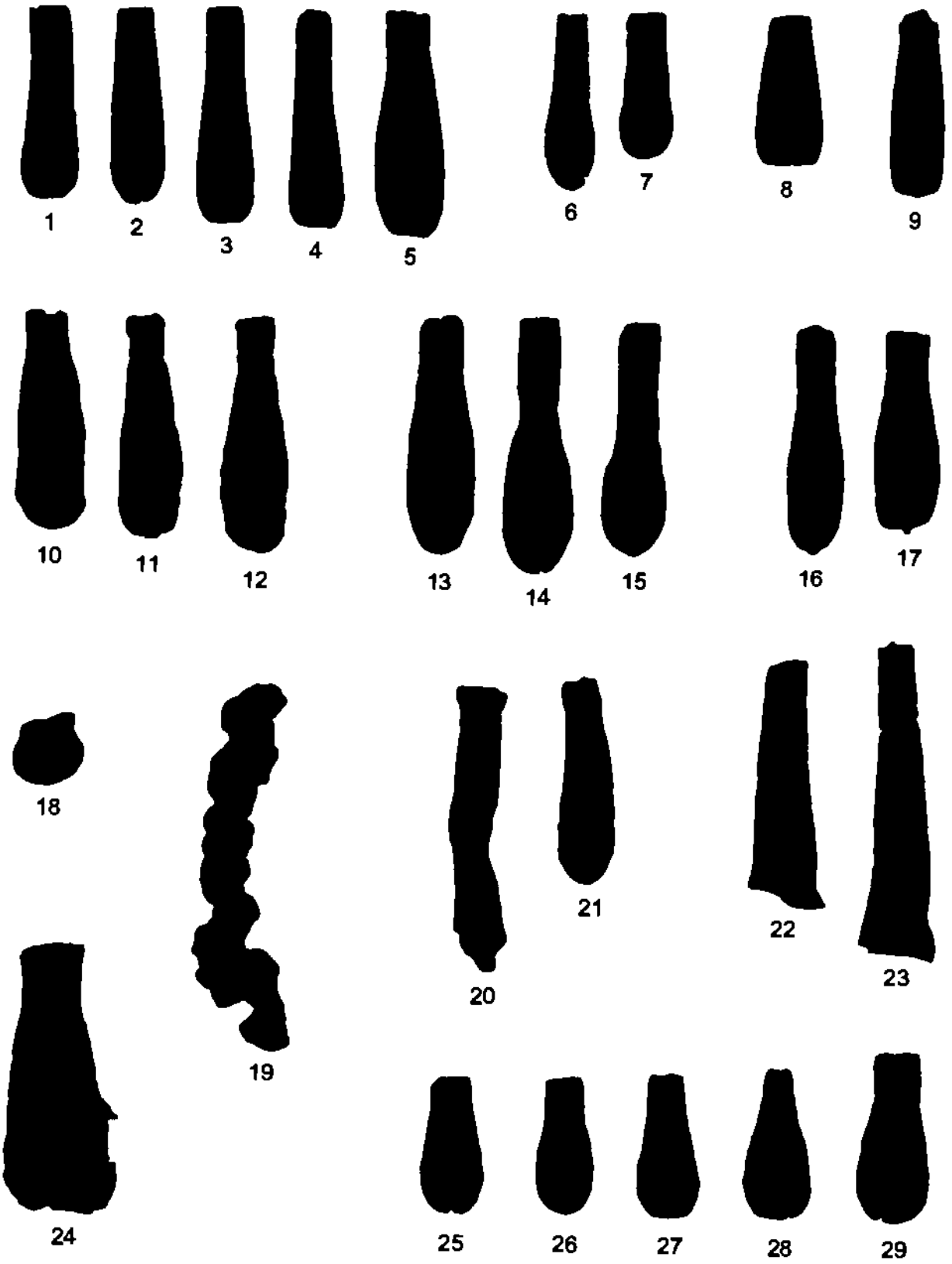

PLATE 4

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-3. *Cyathochitina dispar* Benoit & Taugourdeau 1961, WBS34-08, 26, 09, *I. v. maximus* Zone.

Figs. 4-9. *Cyathochitina calix* Eisenack 1931.
4. WBS28A-06, *I. v. lunatus* Zone.
5. CHN9.17AKZ-12, *T. akzharensis* Zone.
6, 8. WBS34-18, 10, *I. v. maximus* Zone.
7. WBS23C-10, *D. bifidus* Zone.
9. WBS52A-08, *U. austrodentatus* Zone.

Figs. 10-14. *Cyathochitina* sp.
10. CHN9.17AKZ, *T. akzharensis* Zone.
11, 12. WBS23C-15, 14, *D. bifidus* Zone.
13. WBN18A-14, *T. akzharensis* Zone.
14. SPI55-09, *T. akzharensis* Zone.

Fig. 15. Graptolite sicula, shown for comparison.

Figs. 16-22. *Tanuchitina* sp.; 19, 20, 23, conically shaped vesicles.
16. WBS62-01, *U. austrodentatus* Zone.
17. WBN18A-03, *T. akzharensis* Zone.
18, 19. CHN11.4B-04, 03, *P. fruticosus* Zone.
20, 21. WBN29-15, 16, *D. bifidus* Zone.
22. CHS13.6A-12, *I. v. maximus* Zone.

Figs. 23-25. *Rhabdochitina tubularis* Umnova 1976, CHN9.6BC-08, 05, 04, *T. approximatus* Zone.

Fig. 26. *Lagenochitina tumida* Umnova 1969, WBN18A-13, *T. akzharensis* Zone.

Figs. 27-31. *Rhabdochitina usitata* Jenkins 1967; 29, vesicle with fractured base.
27, 28, 30, 31. WBS34-23, 22, 20, 21. *I. v. maximus* Zone.
29. CHN11.4B-02, *P. fruticosus* Zone.

PLATE 4

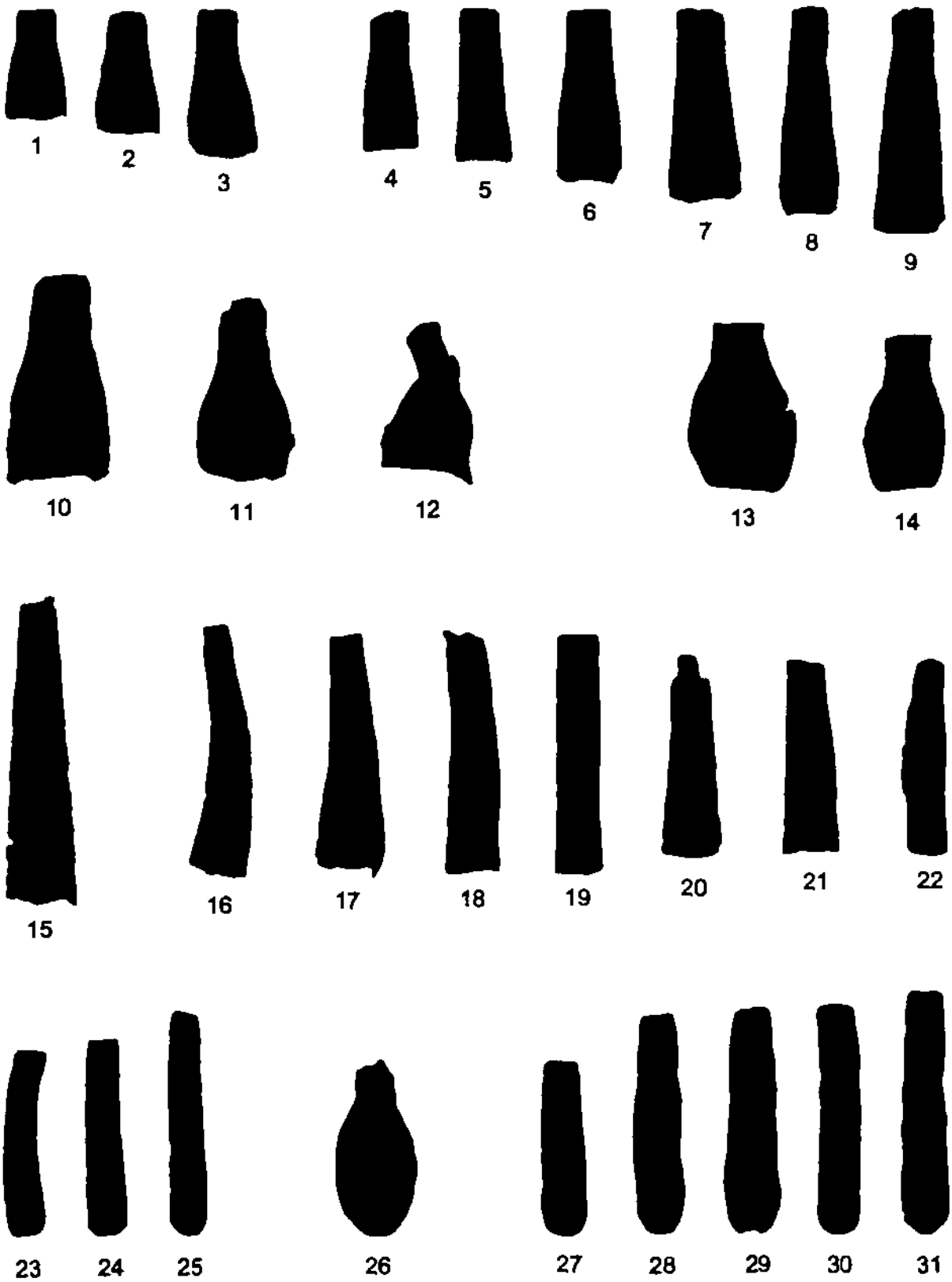
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PLATE 5

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-4. *Lagenochitina* sp. cf. *L. baltica* Eisenack 1931.
1, 2. CHN9.17AKZ-06, 08, *T. akzharensis* Zone.
3. SPI55-09, *T. akzharensis* Zone.
4. WBN18A-10, *T. akzharensis* Zone.

Fig. 5. *Lagenochitina capax* Jenkins 1967, WBN18A-04, *T. akzharensis* Zone.

Fig. 6. *Lagenochitina combazi* Combaz & Péniguel 1972, WBN29-08, *D. bifidus* Zone.

Fig. 7. *Lagenochitina boja* Bockelie 1980, CHN9.17AKZ-04, *T. akzharensis* Zone.

Figs. 8-11. *Lagenochitina cylindrica* Eisenack 1931.
8. WBS62-07, *U. austrodentatus* Zone.
9, 10. WBS52A-03, 02, *U. austrodentatus* Zone.
11. CHS11.30-02, *I. v. lunatus* Zone.

Figs. 12-15, 21. *Lagenochitina destombesi* Elaouad-Debbaj 1988.
12-14. MPS42C-5, 9, 13, *A. victoriae* Zone; 12, vesicle with flattened base.
15. Vesicle with fractured base, CHS11.30-04, *I. v. lunatus* Zone.

Figs. 16-20, 22-28. *Lagenochitina esthonica* Eisenack 1955b.
16, 17. WBN29-02, 06, *D. bifidus* Zone.
18-19, 23, 25, 27-28. WBN18A-04, 05, 11, 06, 09, 08, *T. akzharensis* Zone.
23. Vesicle with fractured base and collarette.
20, 22. SPI55-08, 07, *T. akzhorensis* Zone.
24. CHN9.6BC-01, *T. approximatus* Zone.
26. CHN9.17AKZ-09, *T. akzharensis* Zone.

PLATE 5

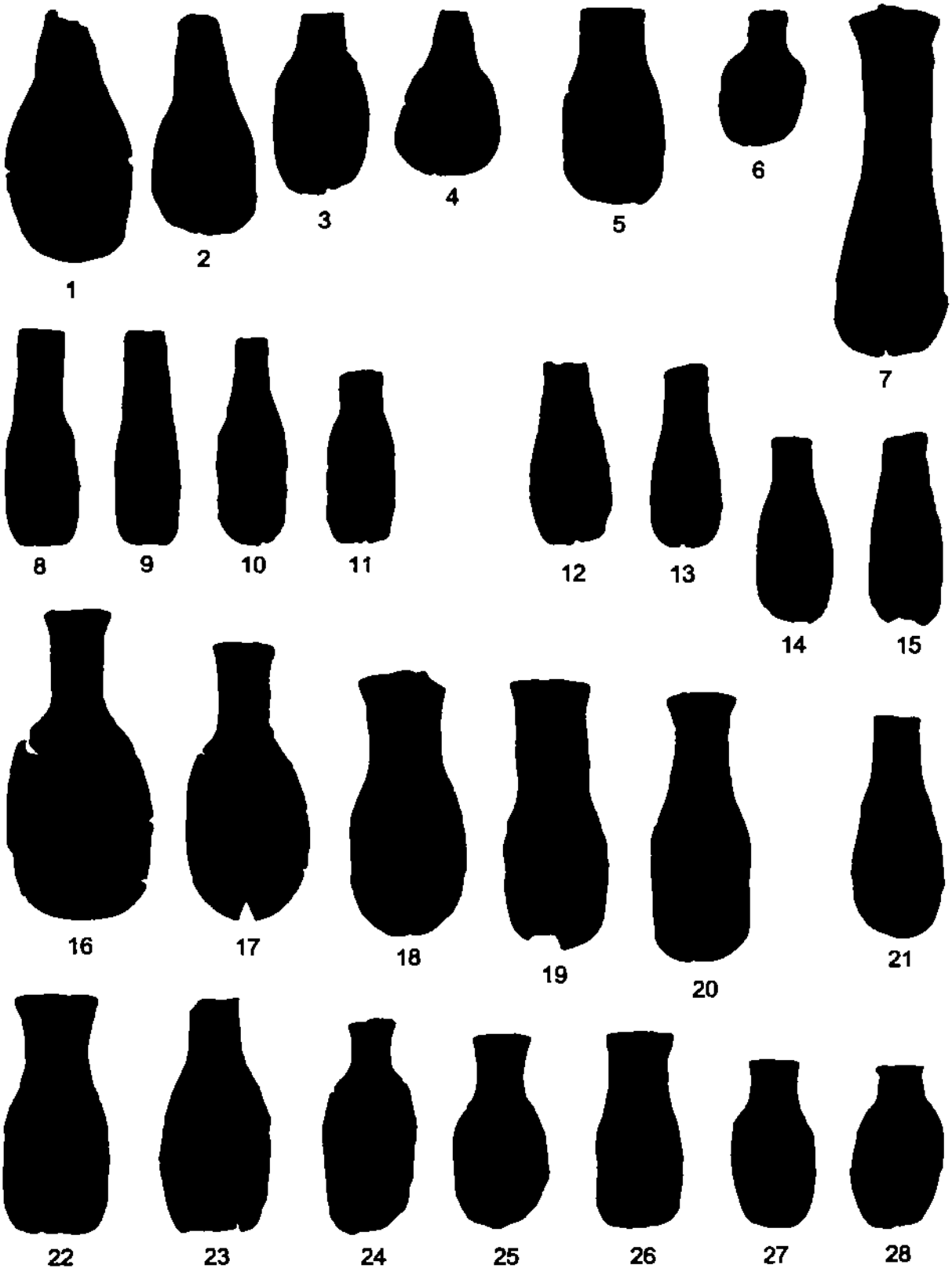

PLATE 6

Reflected light micrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland. All figures x60.

Figs. 1-7. *Lagenochitina maxima* Taugourdeau & DeJekhowsky 1960; 4, vesicle with expanded chamber flanks due to compression; 7, vesicle with fractured collarette.

1. CHN9.17AKZ-03, *T. akzharensis* Zone.
2, 4-7. SPI55-04, 05, 03, 01, 02, *T. akzharensis* Zone.
3. CHN11.4B-01, *P. fruticosus* Zone.

Figs. 8, 9, 16. *Lagenochitina* sp. cf. *L. maxima* Taugourdeau & DeJekhowsky 1960.

8, 9. CHN9.17AKZ-01, 02, *T. akzharensis* Zone.
16. SPI55-05, *T. akzharensis* Zone.

Fig. 10. *Lagenochitina* sp., CHN9.17AKZ-07, *T. akzharensis* Zone.

Figs. 11-13. *Lagenochitina obeligis* Paris 1981.

11. CHN9.17AKZ-05, *T. akzharensis* Zone.
12. WBS23C-03, *D. bifidus* Zone.
13. WBN29-07, *D. bifidus* Zone.

Figs. 14, 15. *Lagenochitina* sp. cf. *L. ovoideo* Benoit & Taugourdeau 1961.

14. WBN18A-12, *T. akzharensis* Zone.
15. CHN9.17AKZ-10, *T. akzharensis* Zone.

Figs. 17, 18. *Amphorachitina conifundas* Poumot 1968, MPS42C-13, 14, *A. victoriae* Zone; 18, vesicle with slightly flattened base.

Figs. 19-21. *Amphorachitina* sp., MPS42C-04, 08, 01, *A. victoriae* Zone; 21, vesicle with fractured base.

PLATE 7

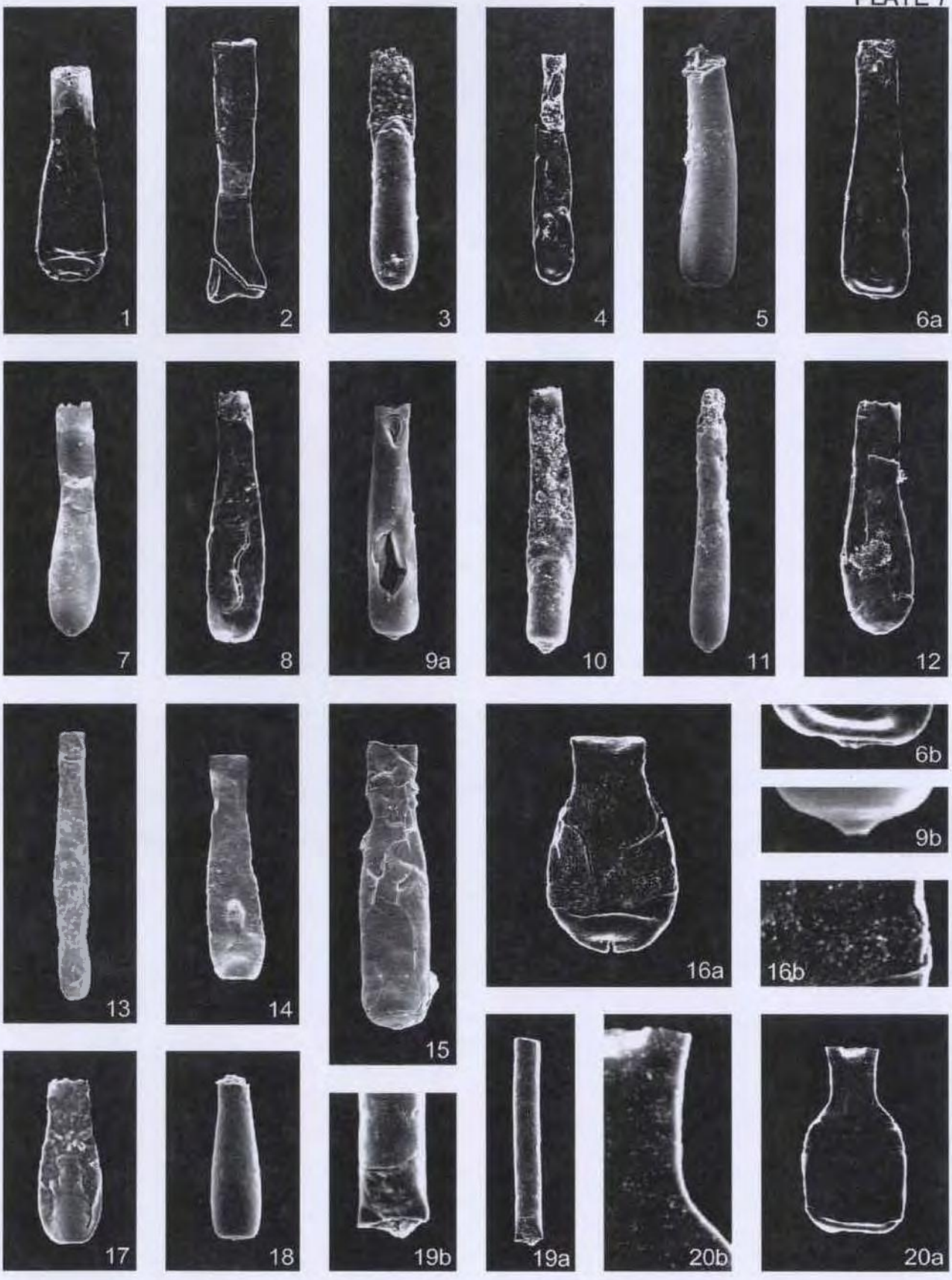

PLATE 7

SEM photomicrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland.

Fig. 1. *Conochitina decipiens* Taugourdeau & DeJekhowsky 1960, CHS13.6A-980075, *I. v. maximus* Zone; x100.

Fig. 2. *Conochitina* sp. cf. *C. elegans* Eisenack 1931, WBN18A-980059, *T. akzharensis* Zone; x83

Figs. 3-5. *Conochitina pervulgata* Umnova 1969.

3. SPI55-980048, *T. akzharensis* Zone; vesicle with anterior flattened, x125.
4. CHS13.6A-980073, *I. v. maximus* Zone; vesicle fractured at neck, x65.
5. WBS23C-980012, *D. bifidus* Zone; x125.

Figs. 6, 9. *Conochitina* sp. E.

6. WBS28A-980026, *I. v. lunatus* Zone; note flattened base; a x100, b x325.
9. WBS23C-980013, *D. bifidus* Zone; note open fracture on chamber, x107.

Figs. 7, 12. *Conochitina langei* Combaz & Péniguel 1972.

7. SPI55-980038, *T. akzharensis* Zone; x107.
12. WBS23C-980024, *D. bifidus* Zone; x120.

Figs. 8, 15. *Conochitina poumoti* Combaz & Péniguel 1972.

8. WBS28A-980022, *I. v. lunatus* Zone; x83.
15. CHN9.17AKZ-980010, *T. akzharensis* Zone; 3-D specimen, x66.

Figs. 10, 11. *Conochitina minnesotensis* Stauffer 1933, SPI55-980041, 980042, *T. akzharensis* Zone; 10, vesicle with anterior portion flattened, x90; 11, vesicle with erosion of the wall around the collarette, x100.

Fig. 13. *Rhabdochitina magna* Eisenack 1931, WBN29-980081, *D. bifidus* Zone; x50.

Fig. 14. *Conochitina raymondi* Achab 1980, WBN29-980089, *D. bifidus* Zone; x83.

Figs. 16. *Lagenochitina* sp. cf. *L. ovoidea* Benoit & Taugourdeau 1961, WBN18A-980058, *T. akzharensis* Zone; 16a x126; 16b, close up of surficial mineral pitting, x400.

Figs. 17, 18. *Conochitina turgida* Jenkins 1967, WBN29-980087, 980085, *D. bifidus* Zone; 17, x107; 18, x100.

Fig. 19. *Tanuchitina* sp., SPI55-980033, *T. akzharensis* Zone; a x60; b, details of the base, x250.

Fig. 20. *Lagenochitina esthonica* Eisenack 1955b, WBN18A-980057, *D. bifidus* Zone; a x126; b, closeup of surface illustrating mineral crystallization granules, x350.

PLATE 7

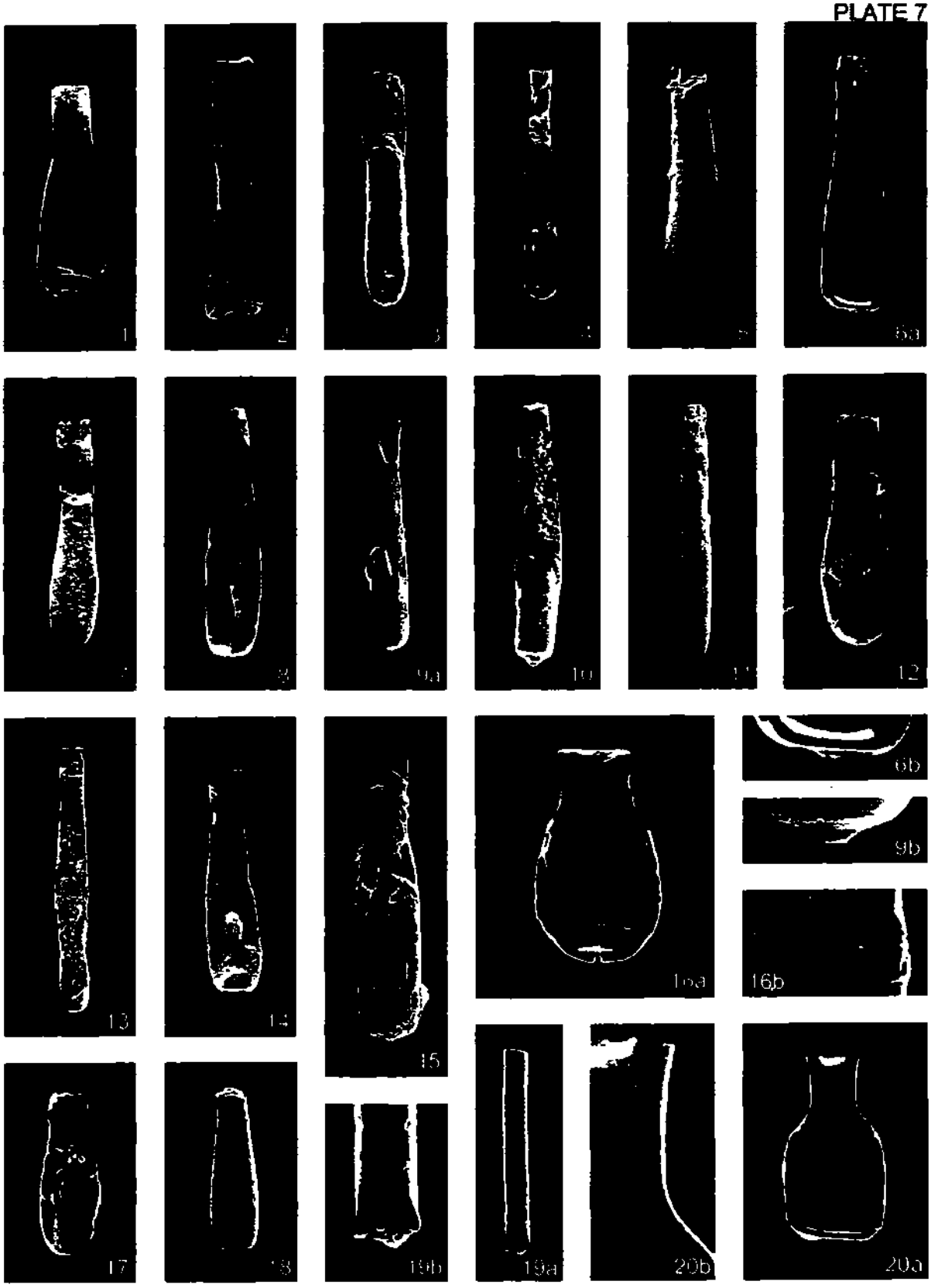

PLATE 8

SEM photomicrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland.

Figs. 1, 2, 16-18, 21. *Lagenochitina esthonica* Eisenack 1955b.
1, 2. WBN18A-980051, 980053 *T. akzharensis* Zone; 1 x83; 2 x125.
16, 17. SPI78-980065, 980064, *I. v. maximus* Zone; 16 x100; 17, x90.
18. WBN29-980082, *D. bifidus* Zone; x83.
21. CHN11.4B-980069, *P. fruticosus* Zone; x107.

Figs. 3, 4, 7-9, 13, 14, 19. *Lagenochitina maxima* Taugourdeau & DeJekhowsky 1960.
3, 4, 8. SPI55-980040, 980031, 980037, *T. akzharensis* Zone; 3, x90; 4 x83; 8 x83.
7. WBN18A-980054, *T. akzharensis* Zone; x83.
9, 13. CHN9.17AKZ-980002, 980001, *T. akzharensis* Zone; 9 x83; 13 x90.
14. SPI55-980044, *T. akzharensis* Zone; 14 x66.
19. SPI43I-980076, *A. victoriae* Zone; 3-dimensional specimen, x100.

Fig. 5. *Lagenochitina capax* Jenkins 1967, WBN18A-980055, *T. akzharensis* Zone; x125.

Fig. 6. *Lagenochitina* sp. cf. *L. ovoidea* Benoit & Taugourdeau 1961, SPI55-980050, *T. akzharensis* Zone; x90.

Figs. 10-12, 15. *Lagenochitina obeligis* Paris 1981.
10. SPI55-980032, *T. akzharensis* Zone; vesicle with flattened base, x125.
11. CHN9.17AKZ-980003, *T. akzharensis* Zone; elongated specimen, x83.
12. WBN18A-980056, *T. akzharensis* Zone; note chamber distortion, x125.
15. WBN29-980083, *D. bifidus* Zone; form resembling holotype, x83.

Fig. 20. *Rhabdochitina usitata* Jenkins 1967, CHS13.6A-980071, *I. v. maximus* Zone; x90.


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PLATE 9

SEM photomicrographs of Arenig chitinozoans from the Cow Head Group, western Newfoundland illustrating various forms of vesicle distortion.

Fig. 1. *Lagenochitina esthonica* Eisenack 1955b, CHN9.17AKZ-980007, *T. akzharensis* Zone; a x100; b, note folding of the right chamber margin giving the vesicle the impression of having an ogival shaped base, x300.

Figs. 2, 4, 5. *Lagenochitina maxima* Taugourdeau & DeJekhowsky 1960.

2. SPI55-980036, *T. akzharensis* Zone; mineral (pyrite?) nodules on the chamber surface; a x85; b x300.
4. SPI55-980044, *T. akzharensis* Zone; flattened base folded back onto vesicle giving the base the appearance of being rounded; a x70; b x250.
5. SPI55-980034, *T. akzharensis* Zone; mineral deposits on the surface of entire vesicle, ax100; b x300.

Fig. 3. *Rhabdochitina* sp?, CHS13.6A-980072, *I. v. maximus* Zone; a x92; b x300.

Fig. 6. Unspecified conochitinid, CHS13.6A-980074, *I. v. maximus* Zone; note distortion of the neck and aperture and fracturing of the vesicle wall, x150.

Fig. 7. *Conochitina homoclaviformis*? Taugourdeau 1961, CHS11.30-980070, *I. v. lunatus* Zone; left lateral margin appears to be deformed (compressed) anteriorly, x100.

Fig. 8. Spheroid (desmochitinid?), MPS42C-980066, *A. victoriae* Zone; note perforations in the vesicle wall, x200.

Figs. 9–11. *Conochitina* sp.; note flattening and expansion of the vesicle's anterior pole causing dramatic distortion of the vesicle's overall shape. This may be a response to catastrophic change in the organisms environment.

9, 11. WBS23C-980018, 980016, *D. bifidus* Zone; 9a x110; 9b x250; 11a x85; 11b x250.
10. WBN29-980086, *D. bifidus* Zone; a x95; b x250.

PLATE 9